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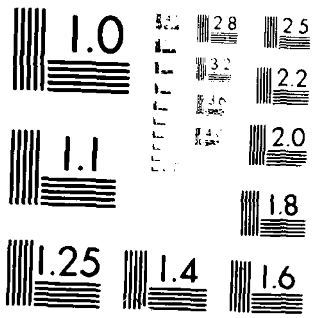

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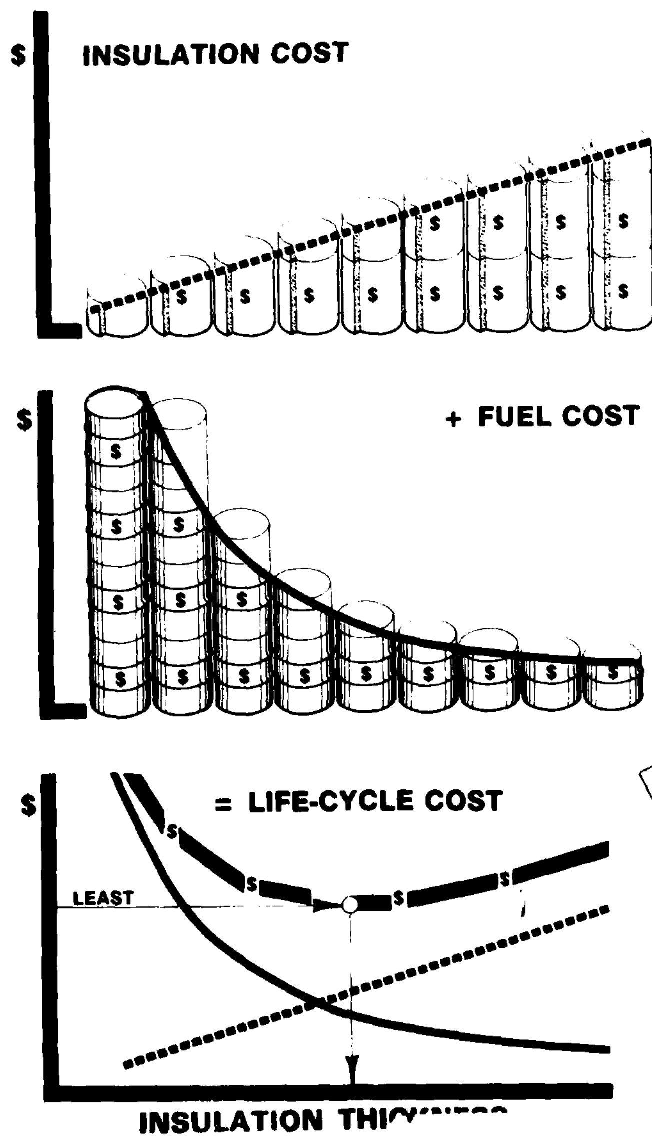
CRREL REPORT 82-27

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Least life-cycle costs for insulation in Alaska



Cover: When more insulation is used in a building, the increased cost of insulation is balanced by savings in fuel costs. The insulation thickness is optimum when its total cost throughout the life of the building is lowest. This is the least life-cycle cost.

CRREL Report 82-27

October 1982

Least life-cycle costs for insulation in Alaska

Stephen N. Flanders and Harold J. Coutts

Prepared for
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Recommendations for economical thicknesses for building insulation result from a study of fuel and construction costs of 12 military installations in Alaska. A comparison between the insulation thickness that a building owner might choose today and what he might choose in 20 years indicates a trend for much thicker insulation in the future. An analysis of how much more expensive a building built today with the thickness that would be appropriate 20 years hence indicates only a small penalty in life-cycle costs for the additional insulation. Therefore, a minimum of R-32 walls and R-62 attics is recommended for most of Alaska.

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PREFACE

This report was prepared by Stephen N. Flanders, Research Civil Engineer, Civil Engineering Research Branch, Experimental Engineering Division, and Harold J. Coutts, Research Civil Engineer, Alaska Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory. This study was conducted as a part of the U.S. Army Corps of Engineers Military Construction Project, 4A762730A142, *Design, Construction and Operations Technology for Cold Regions*.

The authors acknowledge K. Swanson of the Ft. Wainwright Facilities Engineer's Office and L. Leonard, Chief of Energy and Building Research, Alaska Department of Transportation and Public Facilities, for their technical review of this report.

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SUMMARY

This study analyzes the least life-cycle costs (LCCs) for insulation at 12 military bases in Alaska. We base the study on climate and construction cost data used by the U.S. Army Corps of Engineers.

The economic analysis assumes a 25-year project lifetime and 10% time value of money to determine the present value of future expenditures. Fuel oil, coal and natural gas are assumed to have annual escalation rates that cause their prices to rise faster than the aggregate rate of inflation. Construction cost data vary according to location in Alaska.

The construction types for walls include 2 × 4's 16 in. on center, 2 × 6's 24 in. on center, and for thicker walls, double walls of 2 × 4's 24 in. on center, all fully insulated with fiberglass batts. These are typical of Corps of Engineers' designs, even if the wood construction represents furring for masonry construction.

For roofs the study covers attics, built-up roofs (BURs) and protected roof membrane (PRM) construction. Attics are easy to add insulation to, even if more depth of roof structure is necessary. The two types of low slope roof construction incorporate relatively expensive insulation. Their most economical thickness typically has a lower R-value than for attics or walls.

Economic analysis determined that the R-value (the thermal resistance in units of °F-ft²-hr/Btu) should be 21 for walls and 40–62 for attics in most of Alaska. BURs and PRMs, however, would have least LCC R-values of only 12 or 13.

In 20 years, if fuel costs continue to outstrip general inflation, the recommended values become R-32 for walls and R-62 for attics. Those who choose to use construction that will become economically appropriate in 20 years actually pay only a small penalty for their conservatism. Therefore, we recommend this option to hedge against increases in fuel costs and to save fuel supplies.

Since many of the assumptions in the study are based on inexact data, the sensitivity analyses tested the degree to which inaccurate assumptions would alter the conclusions. Because we are dealing with climates that require much insulation and because the addition of an increment of insulation does not offer the dramatic reduction in heat loss that the first increments do, the conclusions are quite insensitive to inaccuracies in construction and heating cost assumptions.

In sum, this analysis demonstrates that using more insulation than conventional economics would suggest costs little extra but in the future will require much less heat input than will contemporary buildings.

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
British thermal unit	0.001055056	joule
degrees Fahrenheit	$t_{°C} = (t_{°F}-32)/1.8$	degrees Celsius
foot	0.3048*	metre
inch	0.0254*	metre

*Exact

LEAST LIFE-CYCLE COSTS FOR INSULATION IN ALASKA

Stephen N. Flanders and Harold J. Coutts

INTRODUCTION

The purposes of this study are to determine representative least life-cycle costs (LCCs) for insulation at Alaskan military bases and to explore the limitations of this kind of economic analysis in formulating building insulation policy at military installations in Alaska.

Life-cycle costing is a method for comparing investment alternatives by converting all present and future costs and revenues into an equivalent form. When choosing an insulation thickness we weigh the added present cost of thicker insulation against future savings in heating costs. In this paper we translate the cost of heating a structure throughout its life into a present value and add it to the cost of construction to make comparisons in 1979 dollars.

We collected data about 1979 heating costs for 12 representative military installations throughout Alaska (Fig. 1). These data, combined with a knowledge of the climate and the construction costs for building types that the U.S. Army Corps of Engineers typically employs, enabled us to compile tables of the most economical insulation thicknesses for these facilities. We determined in all cases that the most economical construction practices would be the same as those now used, even if heating costs were 50% higher than we had assumed.

However, after we collected our data, the price of fuel jumped 187%. The world-wide price that U.S. military installations paid for diesel fuel was $0.449/gal. in 1979. In early 1980 it suddenly became $1.29/gal. We have treated this jump as a one-time adjustment to an unrealistically low initial value. Therefore, we have converted the 1980 price to 1979 dollars and used it alongside the other economic data.

In our analysis the abrupt change in price primarily affected Fort Greely, the remote Air Force sites and Adak Naval Station. In general the least LCC fiberglass insulation for military frame construction in 1979 would have been R-32 for attics and R-21 for walls throughout Alaska. An R-value is the thermal resistance of the construction in units of °F-ft²-hr/Btu. The new price changed the attic values to R-40 and even to R-62 in some cases.

Because they use less expensive fuel, Ft. Richardson and Ft. Wainwright are exceptions. Solely economic considerations indicate that R-21 attics and R-13 walls are appropriate at these bases. This suggests that large users can afford to consume energy less efficiently than the general public.

Further doubt about conventional economic analysis comes when we consider built-up roofs (BURs) and protected roof membranes (PRMs). Adding insulation in these roofs is much more expensive than adding fiberglass to an attic space. As a result economic analysis indicates that the minimum R-12 or R-13 roofs are appropriate for most of Alaska, much less than an attic.

In the body of the paper we explore in greater detail the assumptions that result in such uniform results for a state as economically and climatically diverse as Alaska. In addition we have some recommendations about the limitations of conventional economic analysis for determining insulation policy.

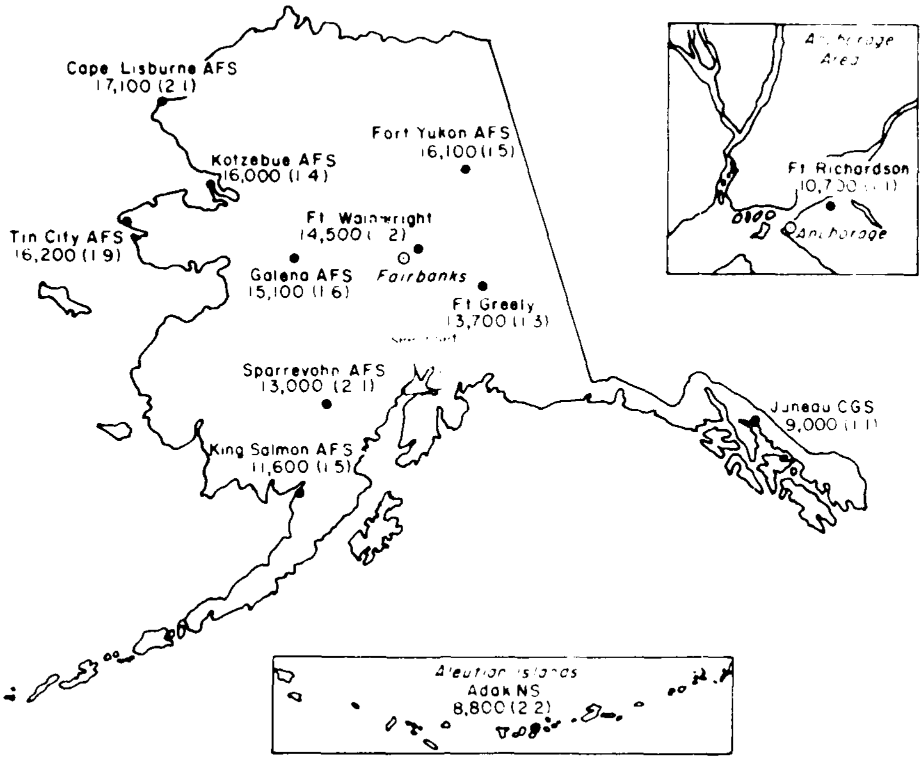


Figure 1. Military installations chosen for the study and their design heating degree-day values. The numbers in parentheses are construction cost factors (CCFs), the multiple that construction costs at the sites are of the costs in Anchorage.

DETERMINING ECONOMIC THICKNESSES FOR INSULATION

Background

Insulation economics frequently receives consideration on a job-by-job basis. The Departments of Energy (DOE) and of Housing and Urban Development have compiled maps showing recommended economic insulating values for the 48 contiguous states. The Department of Defense (DOD) has long imposed thermal performance criteria on building elements such as walls, roofs and floors (DOD 1972). More recently, DOE and DOD have proposed Building Energy Performance Standards. None of these standards has adequately reflected Alaska's climate or construction economics.

Important sources of information on how to address the question of economic insulation thickness for military installations in Alaska include:

1. Griffin (1974), on life cycle cost (LCC) considerations in building design.
2. American Society of Heating and Refrigeration Engineers (ASHRAE 1977) *Handbook of Fundamentals*, with guidance on thermal performance.
3. Eb Rice (1975), with the standard approach on how to choose an economic thickness of insulation.
4. Office of Management and Budget (Schindler, pers. comm. 1979), on what economic parameters to use in LCC calculations.
5. D.G. Stephenson (1976), with a variation on the technique of choosing an economic thickness of insulation that we developed for our study.

Life cycle cost principles

LCC studies of insulation economics involve comparisons of investment alternatives to determine which will cost the least. Expenditures are of three categories: initial costs, annual costs and escalating costs over the economic life of the structure. In this study we use present worth factors to convert all future costs into present costs of equal value. In making an investment, we can make an initial lump sum payment or

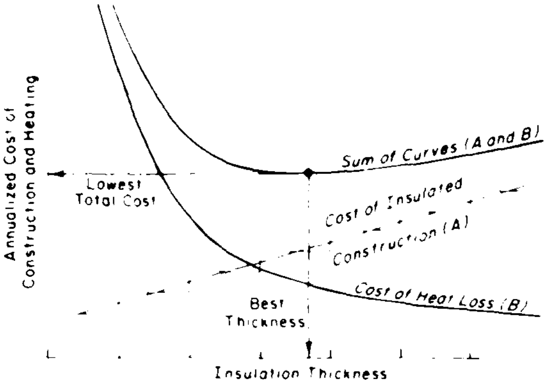


Figure 2. How insulation affects annual cost. Once you've found the "low spot," you're close enough. A little thinner or a lot thicker doesn't change the annual cost much, for near the low spot, what you save for fuel you spend for insulation and vice versa. Illustration and caption reproduced by permission from Rice (1975).

pay a greater sum in continuing investments. For an investment in something that will last 25 years, we would be equally willing to make 25 equal annual payments and collect 10% interest on the outstanding balance or to pay about nine times the amount of an annual payment initially. Therefore, the present worth factor (PWF) for such payments for a 25-year economic lifetime is nine times the amount of a single annual payment. We also use a PWF for an escalating series.

Inflation

In our study, inflation does not enter explicitly into our calculations. We can ignore inflation in considering the economics of government investment because it is likely that no matter how high most costs become, they represent a constant proportion of the money used to fund them. Fuel costs are an exception. We assume that these rise exponentially at a rate that is faster than inflation; therefore, we look at the rate of increase that is the difference between fuel price rises and overall inflation.

The alternative assumption—treating inflation explicity— produces results less favorable to conservation, using our best guesses about an appropriate inflation rate. Such guesses are unnecessary when we simply ignore inflation and, in effect, treat all costs in constant 1979 dollars.

Thermal performance

The ASHRAE (1977) *Handbook of Fundamentals* was the principal source of information for our calculations of thermal performance of building materials. We compared its values with manufacturers' data and found ASHRAE to be generally more pessimistic. This conservative choice helps reflect the imperfections that occur during installation and the degradation of performance during the lifetime of the insulation.

Insulation economics curves

Eb Rice (1975) gives the curve that is most frequently used to represent the economic factors in choosing insulation (Fig. 2). This illustrates that the annual cost doesn't change very much if you choose an insulation thickness somewhere in the vicinity of the lowest point on the curve. More important is the fact that adding considerably more insulation still doesn't cost very much more annually, although it saves more than the economically optimum amount of fuel. Furthermore, linear increases in insulation have diminishing benefits in fuel savings.

Stephenson (1976) represents the most economical choice of insulation thickness differently (Fig. 3). Where Rice shows the absolute cost of the wall affecting the choice of optimum thickness, Stephenson looks only at the cost of adding insulation above a base case cost. Where Rice depicts total annual cost on the vertical axis, Stephenson shows the present worth of heating costs for the life of the project plus the cost of the increment of insulation. Stephenson's graph is especially useful because the horizontal axis can represent different combinations of climate and heating costs per Btu.

The slopes of the lines in Stephenson's graph reflect the thermal resistance (R-value) of the construction. The higher the R-value, the lower the slope and the lower the corresponding lifetime cost of fuel on the vertical axis for a given climate and heating cost combination shown on the lower axis.

Stephenson chooses a base case R-value construction. Any additional insulation results in an increase in the cost of installation. On the graph the line whose slope represents the improved R-value is displaced up from the origin by an amount that represents the increase in cost. The lowest of the intersecting lines above the point on the horizontal axis representing Vancouver,

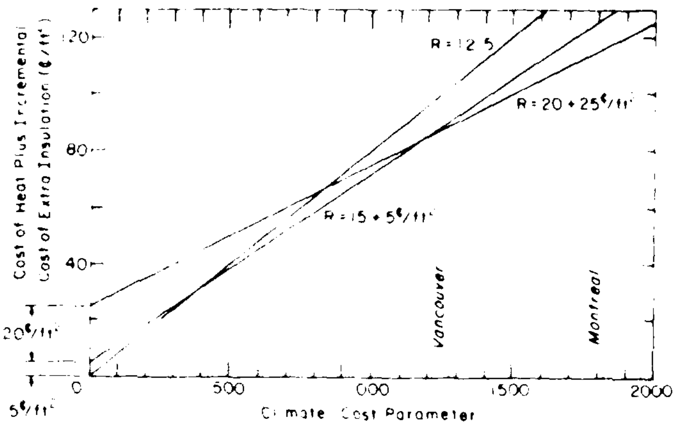


Figure 3. Life-cycle cost comparison of R-12.5, R-15 and R-20 walls. The climate-cost parameter incorporates the cost per Btu of fuel C, the heating degree-days D, a present worth factor P and the efficiency of the heating system E and is equal to 18 CDP/E. Reproduced by permission of D.G. Stephenson.

for instance, represents the least life-cycle cost at that location.

Stephenson's method is limited to comparing alternative insulation thicknesses for a given type of construction. Because costs are relative to the base case, the method cannot provide a way of comparing two types of construction unless one of them is a base case for the other. Therefore, two such graphs (for example, one for a steel sandwich panel wall and one for a frame wall) are unrelated.

LCC assumptions

Rice and Stephenson both employ LCC principles in their examples. These require assumptions about the time value of money to the investor (interest rate) and the economic lifetime of the project involved. The General Services Administration (GSA) has chosen values for use in government construction. It requires an interest rate of 10% per annum and an economic lifetime of 25 years for building projects. GSA advocates these values to avoid having the government make capital expenditures that compete with the private sector for the money supply. The economic lifetime of a building is distinct from its physical lifetime. While a building may stand for 50 years, it may require substantial remodeling after 25 years to adapt it for a new use.

The remaining consideration for life-cycle costing is the difference between fuel price rises and inflation. For guidance on this question we chose U.S. Army Corps of Engineers (1976) figures published for the Energy Conservation Investment Program (ECIP). It recommends an 8% annual differential escalation rate for fuel oil and natural gas and a rate of 5% for coal.

Analysis method for new construction

The insulation economics study incorporates three important facets: the climate-heating cost variable, the R-values of the base case and the increments for each construction type, and the additional cost of insulation increments. These factors were combined as in Stephenson's example to produce LCC comparison curves for selected military installations in Alaska.

Site selection

We selected 12 sites to give a good assortment of locations throughout the state (Fig 1). Initially we targeted Point Barrow Naval Station and Barter Island Air Force Station for inclusion in the study. However, because they make extensive use of waste heat recovery from their generators, there is no charge for heat. Therefore, until these sites run out of capacity from that source, comfort and ease of maintenance are much more important insulation considerations than heating cost.

Climate vs construction costs

Although the locations with higher heating degree-days (HDDs) (Fig. 1) need thicker insulation, these sites are more remote, so increased construction costs generally offset the higher heating costs due to the increased severity of cold. The construction cost factors (CCFs) ranging from 1.1 to 2.2 (Fig. 1) represent the multiple that the construction costs at each site are of the costs in Anchorage. As a result of the interplay between climate, construction costs and heating costs, there is little reason to base economic insulation thickness on location within the state.

Heating costs

We have divided the heating costs into two categories: 1) fuel and 2) operation, maintenance and repair, and capitalization (OMC). These categories are separate because the annual cost of fuel escalates relative to inflation, whereas OMC is assumed to remain at the level of inflation. Most sites employ heating oil (DF-2 diesel) bought at a world-wide military contract rate. At Juneau CGS, fuel comes from commercial vendors.

We collected our heating cost data in 1979 from facilities engineering records at each location; therefore, all our calculations are in 1979 dollars. However, since the early 1980 diesel oil rate of \$1.29/gal is more realistic than the \$0.449/gal for 1979, we converted the 1980 value into 1979 dollars by dividing by 1.12 to account for the rate of inflation since we collected our data.

The military accounting system does not show the cost of transporting the fuel to these sites. We have assumed this cost to be equal to the 1979 barge rate of \$95/ton and have allowed it to escalate with energy costs because transportation is energy-intensive. An alternate method of looking at fuel prices would have been to substitute the price that an ordinary citizen would have to pay. In this case, the government buys fuel inexpensively but because of conservative construction, consumes it only as fast as an ordinary taxpayer would at that location.

OMC costs include the costs of operation, maintenance and repair, and heating plant and distribution system capitalization. At Ft. Wainwright, for example, these values (in \$/10^6Btu) are

Operation (excluding fuel)	1.4
Maintenance and repair	0.5
Capitalization	0.5
Total	2.4

The \$2.4/10^6 Btu value for OMC is about equal to the \$2.1/10^6 Btu spent on fuel. We used this 1.1 ratio of 1979 fuel costs to OMC costs for four Air Force installations where we had to estimate OMC costs, since the ratio was typical of other sites. Further details about heating system charges are in Appendix A.

Present worth factors

We chose PWFs based on these figures for five cases. One case, a conventional analysis of the economic return on insulation investment made in 1979, used $n = 25$ and $i = 10\%$, where n is the economic lifetime of the project in years and i is the annual interest rate. The second case, a more conservative analysis, used $n = 30$ and $i = 3\%$. (A discussion of these two approaches will be presented later.) In each instance a PWF represents a uniform series of payments for OMC and escalating annual fuel cost payments at an 8% differential rate for fuel oil and natural gas and a 5% rate for coal.

The other three cases employ the conventional LCC assumptions of $n = 25$ and $i = 10\%$ and represent the same decision made in 1979 except that fuel costs were raised to their projected values for 1984, 1989 and 1999. These assumptions show how a conventional economic decision decision on insulation thickness changes with time and how rapidly a decision rule becomes obsolete. They allow us to compare a decision in 20 years using conventional assumptions with a 1979 decision using the conservative, "plan ahead" assumption of $n = 30$ and $i = 3\%$. Further details about the choice of PWFs for each case appear in Appendix B.

Climate-heating cost parameter

The above considerations contribute to the climate-heating cost parameter (CHC) defined as

$$CHC = 24 \cdot (5.6)(HDD)[(P/B)F + (P/A)OMC] \quad (1)$$

where

24	factor converting days to hours
5.6	factor accounting for heat sources other than the heating plant
HDD	heating degree-days (based on 65°F)
P/B	present worth factor for escalating series
F	cost of fuel, adjusted for plant and distribution efficiency (\$/Btu)
P/A	present worth factor for uniform series
OMC	cost of OMC adjusted to plant and distribution efficiency (\$/Btu)

Table 1. Climate-heating cost parameter for Alaskan military sites.

All figures represent fuel oil use, except as noted.

Construction cost factor	Site	Heating degree-days	Fuel costs ($/10⁶ Btu)	Oper., maint. and capitalization costs $/10⁶ Btu)	Climate-heating cost ($ · F hr/Btu) Conventional 1979	1984	1989	1999	Conservative 1979
1.1	Ft. Richardson	10,700	1.0*	1.9	7.9	9.9	13	24	23
1.1	Juneau CGS	9,000	8.4	4.0	37	51	71	150	120
1.2	Ft. Wainwright	14,500	2.1⁺	2.5	15	20	26	48	39
1.3	Ft. Greely	13,700	9.5	1.5	56	80	120	250	190
1.4	Kotzebue AFS	16,000	12	5.8**	93	130	180	370	280
1.5	Fort Yukon AFS	16,100	12	5.8**	94	130	180	380	280
1.5	King Salmon AFS	11,600	11	4.5**	60	84	120	250	180
1.6	Galena AFS	15,100	12	5.3**	87	120	170	350	260
1.9	Tin City AFS	16,200	12	4.6	91	130	180	370	280
2.1	Cape Lisburne AFS	17,100	17	1.4	86	120	180	380	280
2.1	Sparrevohn AFS	13,000	15	8.5	98	130	190	380	280
2.2	Adak NS	8,800	14	3.9	55	78	110	230	170

* Natural gas

⁺ Coal

** Estimate

Heating degree-days and heating costs give values for CHC for the selected Alaskan military sites ranked according to their CCF in Table 1.

Escalating and uniform series describe whether future payments occurring on a regular basis in the future will rise according to a compounded rate of increase or remain constant. Plant and distribution efficiency reflect the fact that not all the fuel energy consumed becomes useful heat going into the distribution system because conduction and other losses in distribution prevent delivery of all the heat entering the system. Therefore, for every Btu needed for space heat, extra Btu's must be burned to account for these losses. A typical central heating plant is about 80% efficient, and underground distribution systems lose between 20 and 30% of the energy they receive.

The numbers in the CHC columns in Table 1 are the values along the horizontal axis of a life-cycle comparison graph similar to Figure 2. CHC, when divided by the R-value of the construction, gives the present worth of fuel consumed per square foot of wall or ceiling over the project lifetime. For Ft. Wainwright and an R-13 wall, this would be $1.18/ft² with the conventional 1979 assumptions.

For the years after 1979 we have escalated the fuel costs at their differential rate to a new level, held OMC costs constant and calculated present worth factors just as we would for 1979. Therefore, the CHC values for 1984, 1989 and 1999 are in uninflated 1979 dollars.

The conservative 1979 CHC values eliminate the step of projecting to some future date. Instead, they employ more conservative interest and project-life figures that result in a higher CHC. Such a CHC would occur sometime in the future (if conventional parameters were used) after escalation of fuel costs.

Construction types

Next we'll consider the information necessary to construct the lines on the life-cycle comparison graph for each construction type we are interested in and for each construction cost factor representative of one of our sites. The variables we need are 1) the R-value for each construction and its increments to determine the slopes of the lines and 2) the incremental cost of the insulation, which, when added to the base case, adjusts the line representing the augmented case by moving it up.

The construction types we looked at most closely were those that the Corps of Engineers typically uses in Alaska projects, particularly wooden stud or furred walls, attic spaces, and built-up (BUR) and protected-roof-membrane (PRM) roofs. We did not consider insulation in floors because only special cases, such as in permafrost areas, require a floor to be exposed to the cold, and then they should contain insulation for the full thickness of the joists in most cases.

Table 2. Wall construction assumed for different R-values.

Overall R-value	*Construction members*	*Spacing on center (in.)*	*No. of stud lines*	*Insul. thick. per layer (in.)*	*No. of layers of insulation*
13	2×4	16	1	3.5	1
21	2×6	24	1	5.5	1
32	2×4	24	2	8.5	1
40	2×4	24	2	12.0	1
62	2×4	24	2	8.5	2

Most Corps of Engineers buildings, whether of concrete, wood or metal, employ wooden studs or furring to contain fiberglass insulation. This means that adding insulation affects only this wood structure and incurs similar incremental costs no matter what type of wall it is a part of. Fiberglass insulation comes in R-values of 11, 19, 30 and 38. We obtain higher values by increasing the thickness. Typical wall constructions add an R-value of about 2 to the insulation. Therefore, the corresponding overall wall R-values are 13, 21, 32 and 40. ASHRAE (1977) gives us conservative insulating values for most materials. Appendix C contains the details about the assumed thermal performance for this and the other base cases.

The method for adding insulation is somewhat more complicated in the case of walls than it is for other building elements. Table 2 summarizes the differences in R-values for walls of different constructions.

It is likely that people ignore the 2-in. additional thickness at the floor perimeter when they evaluate the transition from 2 × 4 studs to 2 × 6's. However, an 18-in.-thick, R-62 wall would require considerable extra floor structure to accomodate the intended use within. Consequently we have assumed a penalty on frame wall construction of $10/ft² of floor area consumed by the wall to account for the roof and foundation and $7/ft² to account for the additional area needed for each floor. This implies that the major additional cost is in adding perimeter to the building without significantly affecting the structural system or the utilities. It would therefore be unrealistic to assume a penalty equal to the typical 1979 Anchorage overall cost for a building of at least $100/ft². As a result of the penalties we assumed, the incremental cost of a frame wall for a two-story building is about doubled. We apply the penalty based on a two-story building in this report.

For attic spaces we assumed the use of fiberglass batts. The base case was R-21 with 6 in. of insulation. We looked at insulation thicknesses of 8.5 in. (R-32), 12 in. (R-40) and 17 in. (R-62). In this case we assumed that the density of framing members coming up through the insulation is so low on a square foot basis that the extra material to fabricate a deeper truss would be neglible, considering the insensitivity of the analysis.

Roofs with insulation on the deck (BUR and PRM) employ such expensive insulation material that incremental increases in cost for thicker insulation quickly limit the user to a much lower R-value than would be typical in a fiberglass-insulated attic. In an attempt to employ the least expensive material, we studied the case of a built-up roof containing rigid fiberglass insulation. This resulted in incremental costs for a given R-value improvement that were very close to those of urethane insulation. We penalized the urethane to give it a value of only R-4 per inch, the same as extruded polystyrene, to account for the loss of the freon gas it contains and its vulnerability to moisture. The PRM roof employs extruded polystyrene foam in our examples.

Our cost data for adding insulation come from Godfrey (1979). To adjust the information for use in Alaska, we first converted it to Anchorage costs using a rule of thumb suggested by Chapman (pers. comm.). We multiplied the material cost of an item by 1.3 and the labor component by 1.5 to arrive at the contractor's cost. To account for profit, overhead and contingency in a contract price, the sum of the adjusted labor and material costs was multiplied by 1.35. Finally, we multiplied that result by the construction cost factor (CCF) shown in Table 1 to determine the incremental cost at each site.

Army Regulation 415-17 gives cost factor adjustments for estimating major construction elements according to region. The regional cost factors we used are about 24% less than those in AR 415-17. Tables 3 and 4 indicate that AR

Table 3. Sensitivity of wall and attic R-values to heating costs at selected military installations in Alaska.

Lower limit and upper limit columns show what percentage the actual cost of heating could be of the assumed cost and still result in the same choice of R-value. Blanks indicate where a higher R-value insulation case was not calculated.

Place and component	*Conventional R-value (ft² hr °F/Btu)*	*Lower limit (%)*	*Upper limit (%)*	*Conservative R-value (ft² hr °F/Btu)*	*Lower limit (%)*	*Upper limit (%)*
Juneau CGS						
wall	21	63	190	32	56	10
attic	32	49	100	62	60	40
Ft. Greely						
wall	21	50	140	62	94	
attic	40	90	150	62	45	126
Kotzebue AFS						
wall	32	89	180	62	66	
attic	62	98	280	78	94	
Fort Yukon AFS						
wall	32	99	180	62	72	
attic	62	98	260	78	86	
King Salmon AFS						
wall	32	53	160	40	96	110
attic	32	38	120	62	51	130
Galena AFS						
wall	21	38	110	62	82	
attic	40	71	120	78	91	
Tin City AFS						
wall	21	44	130	62	80	
attic	40	91	140	78	88	-
Cape Lisburne AFS						
wall	21	50	150	62	99	-
attic	32	40	110	62	47	120
Sparrevohn AFS						
wall	21	45	130	62	99	--
attic	40	95	140	62	47	120
Adak NS						
wall	21	85	250	32	79	150
attic	32	62	170	62	82	230

Table 4. Sensitivity of wall and attic R-values to heating costs at Ft. Richardson and Ft. Wainwright, Alaska.

Lower limit and upper limit columns show what percentage the actual cost of heating could be of the assumed cost and still result in the same choice of R-value. Blanks indicate where a lower insulation R-value case was not calculated.

Place and component	*Conventional R-value (ft² hr °F/Btu)*	*Lower limit (%)*	*Upper limit (%)*	*Conservative R-value (ft² hr °F/Btu)*	*Lower limit (%)*	*Upper limit (%)*
Ft. Richardson						
wall	13	--	290	21	100	300
attic	21	—	350	32	78	170
Ft. Wainwright						
wall	13	-	170	21	64	190
attic	21	—	130	32	49	130

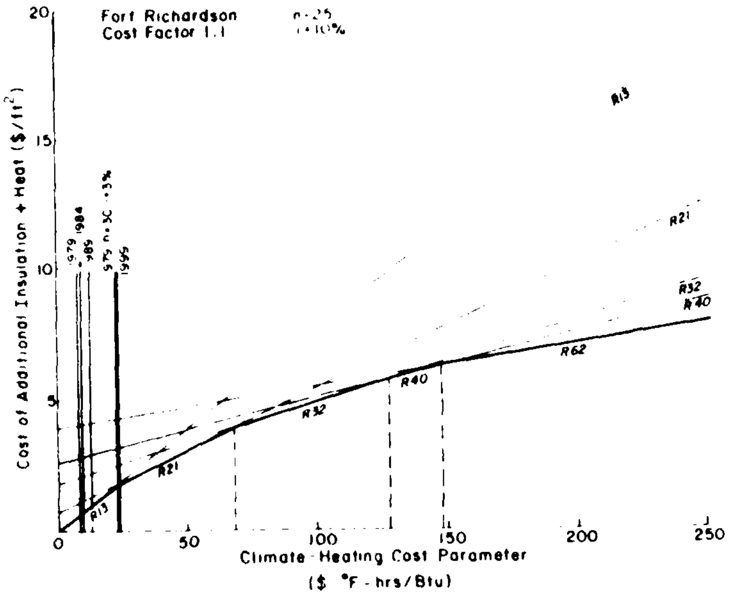


Figure 4. Life cycle cost comparison curves for walls insulated with fiberglass batts at Ft. Richardson. The lower sloped lines represent higher R values. They save heating costs but cost incrementally more to build including a penalty for the floor, roof and foundation space they consume. Therefore, the intercept on the vertical axis is higher. The vertical lines represent Ft. Richardson's climate-heating cost parameters for different dates and LCC assumptions. Where the vertical line intersects the diagonal is the LCC for the insulation option.

415-17 would cause us to choose the next lower insulation option in three of the wall selections and five of the attic selections. This would bring greater uniformity to the choice of R-21 walls and R-32 attics in Alaska under conventional economic assumptions. The method we used instead of AR 415-17 has worked well for the Alaska District of the Army Corps of Engineers.

Sample results

Now, with all the elements necessary to construct the LCC comparison graph, let's look at the results for framed walls. (The LCC comparison graphs of other construction types are in Appendix D.) Figure 4 shows the heating cost lines for different insulation thicknesses becoming less in slope as the R-value increases. At the same time their lower left ends start higher up from the origin as the cost of adding insulation increases. The vertical lines marked with dates represent the CHC values for Ft. Richardson in Table 1. The 1979, 1984 and 1989 CHC values all indicate R-13. Not until 1999 will fuel costs have escalated high enough to warrant R-21 walls, according to conventional economic analysis. This corresponds to the conservative case for 1979. Even so, the latter two cases are marginal and could also represent the lower insulation value.

Figure 5 uses the same LCC comparison curve as Figure 4 because Juneau has the same CCF of 1.1. However, the Juneau CGS buys much more expensive fuel and has higher OMC costs, therefore, in 10 years the indicated values for walls might change from R-21 to R-32. In 20 years the economic value might progress through the narrow band of R-40 toward R-62.

The increase of CCF to 1.2 for Ft. Wainwright (Fig. 6) shifts the lines upward, moves the break points between lines outward, and narrows the R-40 band. In 10 years the CHC will have moved into the region of R-21, but will have only progressed halfway through it by 1999. The CHC for Ft. Greely, with CCF = 1.3 (Fig. 7), will move from R-21 to R-62 in 20 years. If it were not for Ft. Wainwright's low fuel cost, it might be making a transition similar to Ft. Greely's. The graphs for the remaining sites are in Appendix D.

LCC penalty for the conservative option

The LCC comparison curves allow us to assess the added expense of choosing more insulation than conventional economic analysis indicates. Consider Ft. Greely in Figure 7. The first vertical line on the left represents the CHC for 1979 under conventional GSA assumptions. The lowest curve it intersects is R-21 at $3.3/ft². This offers the lowest LCC under the conventional assumptions. The same vertical CHC line intersects the line for R-32 at $3.8/ft². Thus, if we choose this more conservative insulating value, we incur a $0.5/ft² penalty. This, together with the $0.3/ft² LCC penalty for choosing an R-62 instead of an R-40 attic space, represents a small additional cost when totaled for the entire building, yet the building would incur 34% less heat loss through walls and 35% less through the attic. Appendix E outlines the cost penalties at the selected sites.

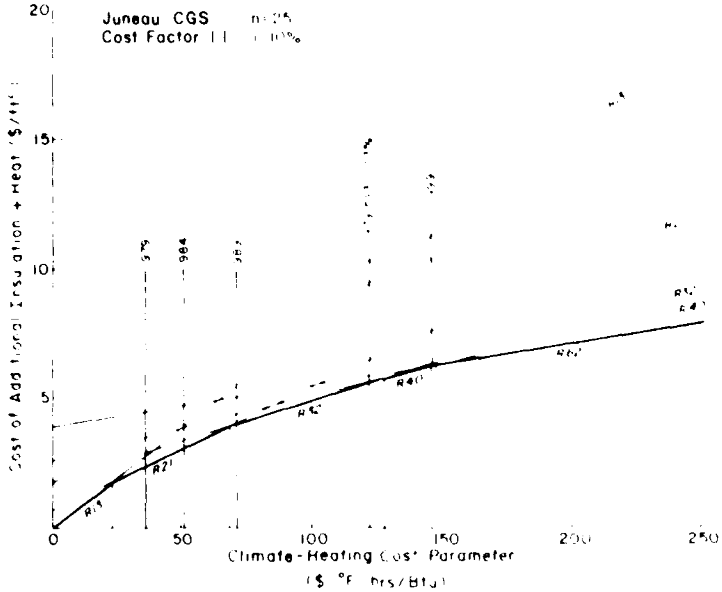


Figure 5. Life-cycle cost comparison curves for walls insulated with fiberglass batts at the Juneau Coast Guard Station. Compare this with Figure 4 and note that the diagonal lines are identical since Juneau has the same construction cost factor as Ft. Richardson. However, since the heating costs are so much greater the vertical lines intersect the diagonal much farther out.

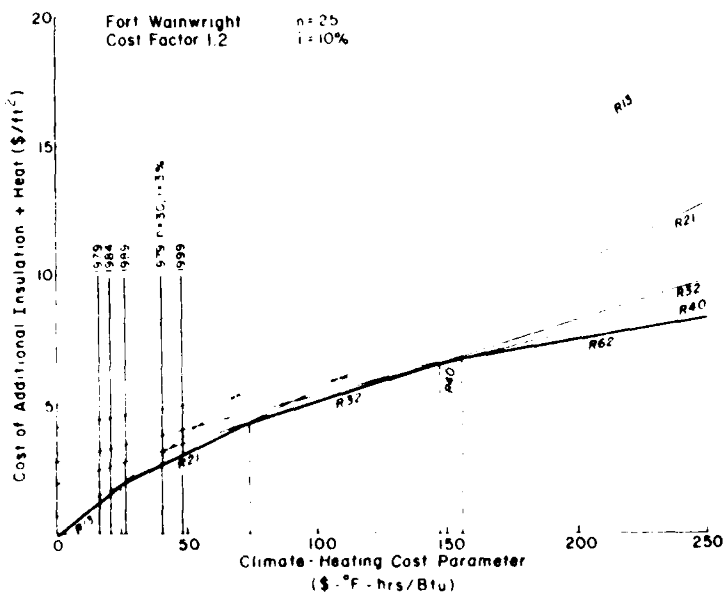


Figure 6. Life cycle cost comparison curves for walls insulated with fiberglass batts at Ft. Wainwright. Note the effect of using a cost factor of 1.2 instead of 1.1 as in Figures 4 and 5.

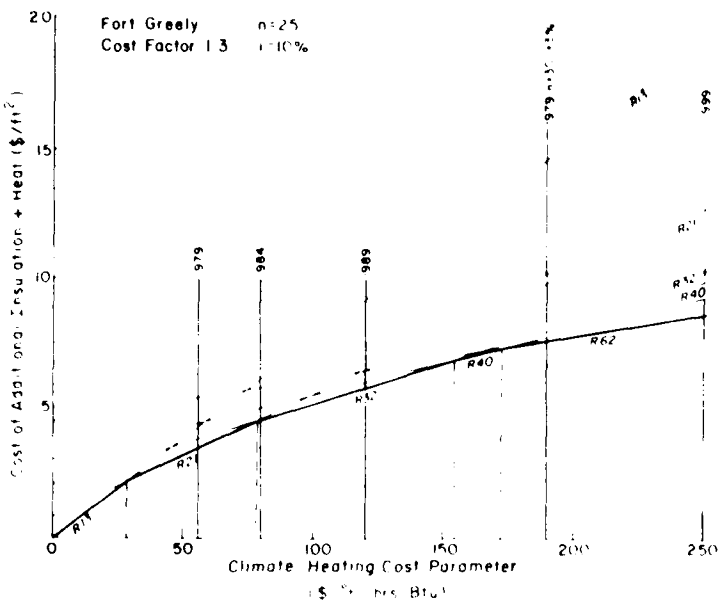


Figure 7. Life-cycle comparison curves for walls insulated with fiberglass batts at Ft. Greely.

Analysis method for reinsulating existing construction

Reinsulating an existing building is a significantly different problem for LCC analysis. Insulating attic space is not very different from new construction, except that there is not the option of deepening the truss space. Adding insulation to an existing BUR or PRM roof is probably uneconomic, since it was uneconomic when the roof was new. There is a case for adding insulation only when the roof insulation must be exposed for repair anyway.

Building walls present conflicting considerations for reinsulating existing construction. Two insulating strategies are available: add insulation to an outside surface or fill a void within the wall. There are usually many obstacles to adding insulation from the indoor side, including disruption of the inhabitants. From the outdoor side, the cost of trimming the added thickness around openings and under gables and eaves can be significant. In the case of filling the wall, gaining access to the interior and then patching the points of entry can represent over half the total cost.

In all cases for walls and roofs, two variables determine whether the reinsulating measure is economic: the degree of thermal improvement which results in the fuel savings and the amount that the cost of construction offsets the present worth of the fuel to be saved. Figure 8 depicts fuel savings as a function of the improvement in U-value ($\Delta U = 1/R_{initial} - 1/R_{reinsulated}$) for lines representing CHCs as great as 98. The 1979 CHC lines for Ft. Richardson, Ft. Wainwright, Ft. Greely and Sparrevohn AFS come from the values in Table 5. Three examples represent improvements in U-value. Wall A is a 2 × 6 frame wall with 2 in. of fiberglass inside. Wall B is a 2 × 4 frame wall with no insulation and wall C is an empty 2 × 6 wall.

If we employ blown-in fiberglass with an R-value of 2.2/in., then we improve the U-values of walls A, B and C by about 0.04, 0.14 and 0.17, respectively. Fuel savings for each square foot of wall C would be about $17 at Sparrevohn and $1.35 for Ft. Richardson, using the conventional n = 25 years and i = 10% annually and assuming that the work is done in conjunction with remodeling that resets the clock on the building's economic lifetime. Those amounts, then, represent the maximum price per square foot for a thermally effective reinsulating job. To put these figures in perspective, consider that such a blown-in insulation job might cost about $1.38/ft² for a Ft. Richardson 2 × 6 frame wall. This would make the job tough to justify economically. At Ft. Wainwright, if the same job cost $1.66/ft², the $2.62/ft² fuel savings would easily warrant reinsulating.

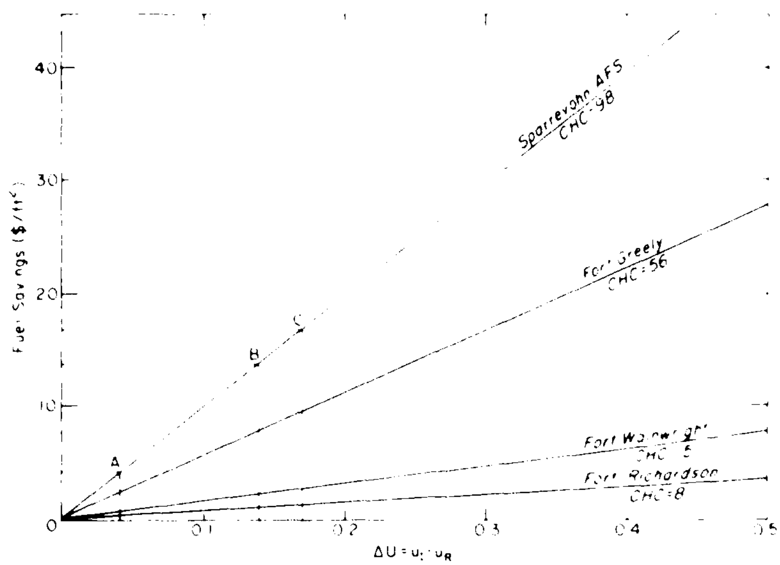


Figure 8. Fuel savings as a function of thermal improvement. The slopes of the lines represent the Climate-Heating Cost Parameter for four sites. The fuel savings (vertical axis) from a thermal improvement are proportional to $\Delta U = U_{initial} - U_{reinsulated} = 1/R_{initial} - 1/R_{reinsulated}$.

Table 5. R-values of walls insulated with fiberglass batts for times of choice at selected military installations in Alaska.

Site	*Conventional LCC analysis* 1979	1984	1989	1999	*Conservative LCC analysis* 1979
Ft. Richardson	13	13	13	21	21
Juneau CGS	21	21	32	40	32
Ft. Wainwright	13	13	21	21	21
Ft. Greely	21	32	32	62	62
Kotzebue AFS	32	32	40	62	62
Fort Yukon AFS	32	32	40	62	62
King Salmon AFS	21	21	32	62	40
Galena AFS	21	32	32	62	62
Tin City AFS	21	32	32	62	62
Cape Lisburne AFS	21	21	32	62	62
Sparrevohn AFS	21	32	32	62	62
Adak NS	21	21	21	32	32

Walls B and A offer less opportunity for thermal improvement; they intersect earlier with the CHC lines for each base, indicating a smaller justifiable reinsulating budget. Appendix F is a graph for charting the fuel savings for any thermal improvement.

SENSITIVITY AND LONGEVITY OF THE RESULTS

Sensitivity

The important variables in determining economical insulation thicknesses are heating costs, the cost of including an additional increment of insulation thickness in the building, and the heating degree-days for the location at hand. The climatic data are the most reliable of the three forecasting variables. The cost of insulation is derived from accepted sources of construction cost data. With adjustments for variations in location within Alaska, this can be an adequate common point for comparison. Of the three principal variables the data concerning heating costs at various military installations in Alaska have the greatest likelihood for error. Estimated contract costs for standard construction techniques such as insulating stud frame walls may be quite accurate on the average, but how does the variation of individual prices affect the economic picture?

Heating costs

If the cost of heating is higher than we assumed in our study, then the next insulation increment would appear more attractive. If construction costs are higher than we assumed in our study, less insulation looks more attractive. Because the amount of insulation we use varies in incremental thicknesses of several inches rather than continuously, we may choose the same thickness of insulation for a spectrum of heating costs. This can make the economic choice of insulation thickness quite insensitive to inaccuracies in our construction and heating cost assumptions.

The sensitivity of choice of insulation thickness to inaccuracies in our assumptions is more important for framed (and furred) walls and attic spaces than it is for BUR and PRM roofs because regulatory requirements for minimum thermal performance, rather than energy economics, will probably determine the thickness of insulation for the latter two roof types.

With conventional LCC assumptions most military facilities in Alaska would employ at least R-21 walls and R-32 attics. (Ft. Richardson and Ft. Wainwright are exceptions.) These results hold true even for a significant range of possible error in our heating cost assumptions (Table 3). Some possible sources of error include the escalation rate of the price of fuel, the cost of transporting fuel to the sites, the labor and material costs of operation, the maintenance and capitalization costs of heating plants, and the cost of fuel.

Table 3 demonstrates that the conventional present worth of the assumed heating costs would have to average 160% of what we assumed to indicate the choice of a higher R-value in walls or attics.

With conservative LCC assumptions most of the remote Air Force Stations would employ R-62 walls and R-78 attics. Some sites would use R-32 walls and R-62 attics: Juneau CGS (because of a milder climate) and Adak NS (because of high construction costs and a milder climate).

Construction costs

The results of our study are also quite insensitive to variations in incremental costs of insulation. Higher fuel costs justify bigger and more expensive increments of insulation. Conversely, as construction costs for adding insulation increase, they offset the effects of fuel costs and make additional insulation more difficult to justify. Therefore, any possible error in our construction cost assumption has an effect similar to that demonstrated in Table 3 for fuel cost inaccuracies.

Special cases

Ft. Richardson and Ft. Wainwright are exceptions to the uniform R-values indicated for military installations throughout Alaska. Conventional economic analysis generally suggests R-21 walls and R-32 attics, while at these locations it suggests R-13 walls and R-21 attics. Instead of the R-32 walls and R-62 attics more conservative analysis generally suggests, these locations would have R-21 walls and R-32 attics.

These two major Army bases buy heating fuel that is inexpensive by most standards. Only in the case of attic insulation at Ft. Wainwright would a 30% increase in heating costs over those we assumed indicate increased insulation value in either the conventional or conservative scenarios (Table 4).

Longevity

How long will our results remain valid? The DOE will probably govern insulation policy. At the same time, any building component should meet minimum conventional life-cycle cost economic criteria. Tables 5 and 6 demonstrate how the choice of insulating value for frame walls and attics would change over the 20 years following 1979.

According to Table 5, only after 10 years would the accumulated increase of fuel costs over insulation costs begin to change the choice of economical wall insulation in most cases. Juneau CGS, Kotzebue AFS and Ft. Wainwright would have changed to at least R-32 walls. The remote Air Force sites all would have reached R-62. The last column demonstrates how a choice of insulation in 1999 using conventional

Table 6. R-values of attics insulated with fiberglass batts for times of choice at selected military installations in Alaska.

	Conventional LCC analysis				*Conservative LCC analysis*
Site	*1979*	*1984*	*1989*	*1999*	*1979*
Ft. Richardson	21	21	21	32	32
Juneau CGS	32	40	40	62	62
Ft. Wainwright	21	32	32	32	32
Ft. Greely	40	40	62	78	62
Kotzebue AFS	62	62	62	78	78
Ft. Yukon AFS	62	62	62	78	78
King Salmon AFS	32	40	62	78	62
Galena AFS	40	62	62	78	78
Tin City AFS	40	62	62	78	78
Cape Lisburne AFS	32	40	62	78	62
Sparrevohn AFS	40	62	62	78	62
Adak NS	32	32	40	62	62

analysis matches our conservative 1979 choice of insulation in most cases.

The choice of insulation value for attics with fiberglass batts is more sensitive to time than the choice for wall insulation (Table 6). Within five years most locations would require a higher R-value in new construction. After 20 years most remote locations would require R-78. Note that the conservative LCC analysis for 1979 again agrees with what the conventional choice in 1999 would be in all but four cases.

In sum, the choice of wall and attic insulating values of R-21 and R-32 under conventional assumptions or R-62 and R-78 under conservative assumptions for most locations in Alaska is quite insensitive to any inaccuracies in our assumptions about heating costs or construction costs. In fact, our conventional assumptions result in insulation values consistent with standard practice.

However, the analysis of the longevity of results indicates that the standards for insulation thickness should be adjusted upwards about every five years, given conventional LCC assumptions. This high rate of obsolescence indicates that using extra insulation in a new building to ensure that the owner will be satisfied in the future is worth the small penalty.

The results of our conservative assumptions are in harmony with the current choices of people who consider saving fossil fuel for future generations to have a higher priority than saving money. The conservative assumptions would not be as likely to require a change in insulating capability because additional insulation would not save very much.

RECOMMENDATIONS

We recommend more conservative insulation values than conventional economics indicates. We advocate a minimum of R-32 walls and R-62 attics for most of Alaska. We have demonstrated that the LCC penalty is slight for the benefit gained.

Saving money vs saving energy

Energy conservation saves in two dimensions, money and fuel. Conserving one does not necessarily save the other. A few decades ago economic analysis of the appropriate amount of insulation in buildings would have indicated the need for very little, because burning fuel was less expensive than adding more insulation. In retrospect we wish we had ignored the sound economic considerations of the past and paid a little more for additional insulation that would have saved fuel that is now gone forever.

Today we see fuel resources as limited in supply and appreciate that what we consume now may not be available later, even in some economical substitute form. Exponentially dwindling developed petroleum reserves result in exponentially increasing energy costs. Life-cycle cost analysis can accommodate such anticipated increases in prices within the economic horizon of the project at hand. However, there is little incentive for an individual who is trying to make financial resources stretch as far as possible in the next 20 years to make sacrifices for the sake of conserving resources for people living 100 years from now. The future holds too much uncertainty, even if the individual plans that far ahead.

A nation, however, lives longer than its individual citizens, just as a body lives longer than its constituent cells. Therefore, it makes sense for a nation to plan beyond the human life span. There may be a technological solution to the high cost of energy, but there are no guarantees. If technology doesn't solve the problem, people in the future will be much better off if we save fuel resources in preference to saving money. If we knew and valued the future as we do the present, saving money and husbanding fuel resources might be the same policy.

Energy economics conservatism

For this reason we recommend that economic analysis of energy-related investments be more conservative than the conventional assumptions of a 25-year economic life and a 10% return on investment that many government agencies currently employ. If we assume that construction costs roughly parallel inflation while the rate of increase of energy costs is higher than inflation, then economic analyses of insulation thickness may be as radically different 20 years from now as today's analyses are from those of 20 years ago. Our calculations indicate that conservative assumptions of a 30-year economic life for new construction and a 3% return on investment result in the same insulation thickness decision today as would be made with the conventional lifetime and interest figures after 20 years of fuel price increases that exceed the inflation rate. However, the present worth of the decision based on the conservative parameters is less than for a decision made in the future with the conventional parameters.

The policy of spending a little more now to save later would be difficult for any government agency to adopt voluntarily because it would make new construction more expensive in a time when budgets are tight. This is because government agencies' planning horizons correspond more to the career spans of politicians or civil servants than to the lifetime of a person, family or nation. However, added insulation thickness is a small part of total building costs and offsets added heating and ventilating capacity.

The results of the conservative economic analysis for government projects show that typical frame construction should employ at least R-62 attics and R-32 walls throughout Alaska, with the same exceptions as before. Ft Richardson and Ft. Wainwright should have R-32 attics and R-21 walls. However, whether the conventional (10%, 25 yr) or the conservative (3%, 30 yr) economic analysis is used, major installations should buy fuel inexpensively but consume it as if it were as expensive for them as it is for the average citizen. Competition for fuel sources from the private sector may drive up the prices these bases pay. Therefore, added insulation is a good hedge against inflation. This policy would put the insulation thicknesses for the major military installations in line with those for other sites in the state.

Most large buildings employ flat roofs rather than sloped roofs with attic space. The overall economic considerations in choosing flat over sloped roofs are beyond the scope of this paper. However, even conservative economic parameters for determining insulation thickness indicate BURs should have an R-20 rating in most cases and PRMs an R-29, while most attic space should have an R-62. We advocate roofs that accommodate much insulation inexpensively.

A person in Anchorage or Fairbanks paying 80 cents per gallon of fuel oil in 1979 would want to insulate frame construction with an R-32 attic and R-21 walls, according to our conventional assumptions. Conservative assumptions indicate R-62 throughout.

In the year 2000 the conventional economic choice may well be R-62 walls and R-78 attics. Employing those values today would incur an initial penalty, but result in energy savings. The net LCC penalty would ensure against unexpectedly high fuel cost increases. Also, the owner of such a building 20 years from now would be well satisfied with the building's thermal performance.

*The penalty for choosing the conservative in-*sulating values over these dictated by conventional economics would be slight. For example, opting for R-32 walls and R-62 attics in place of R-19 and R-32 would cause a LCC penalty of about 0.1% of the construction cost of a typical barracks or housing multiplex at a remote Air Force site. R-40 walls and R-78 attics would represent a 0.4% LCC penalty. For an R-32 and R-62 combination at Ft. Richardson, the penalty would be 1.1% of the construction cost.

This penalty is the cost of the additional insulation less the present worth of the fuel to be saved over a 25-year economic life at 10% interest. (Appendix E gives further details on LCC penalties for conservation.) Unfortunately, although the LCC penalties are slight and represent an insurance premium well spent to cover unexpected energy cost increases and to satisfy the building owner of 20 years hence, the initial cost penalties are harder to ignore. In an era of tight budgets, construction cost increases of 0.4% to 1.1% of the conventional building cost for increasing the insulating value of walls and attics to R-32 and R-62 at the major bases and R-40 and R-74 at remote sites are not likely to receive approval.

Building energy performance standards

The above recommendations for economic thicknesses for insulation do not contradict the Building Energy Performance Standards (BEPS) that the Department of Energy has developed. Rather than require that each building have a specified thermal value for each component, the BEPS require that a building as a whole consume not more than a specified amount of fuel. This gives the designer flexibility to increase glass area, for example, but pay the penalty elsewhere in increased thermal efficiency. The emphasis of the BEPS is on saving energy, rather than dollars.

A designer should try to satisfy the requirements of the BEPS and at the same time minimize the life cycle cost of each component in a way consistent with the intended use of the building.

CONCLUSION

In this paper we have outlined the basis for formulating an insulation performance standard for military installations in Alaska. Given the choice between conventional life-cycle cost economic assumptions and more conservative assumptions, we recommend the latter because they represent a planning horizon consistent with the nation's life span (which is measured in generations) and they prevent rapid obsolescence of insulation criteria.

We also have shown how to assess quickly the economic return on making a thermal improvement to an existing structure. We hope this will aid designers and facilities engineers in Alaska to make sensible energy conservation decisions.

LITERATURE CITED

ASHRAE (1977) *Handbook of Fundamentals*. New York: American Society of Heating, Refrigerating and Air Conditioning Engineers.

DOD (1972) *Construction Criteria Manual*. DD 4270.1-M. Washington, D.C.: U.S. Government Printing Office.

Godfrey, Robert S. (Editor) (1979) *Building Construction Cost Data 1979*. Duxbury, Massachusetts: Robert Snow Means Co., Inc.

Stephenson, D.G. (1976) Determining the optimal thermal resistance for walls and roofs. Building Research Note No. 105, National Research Council of Canada, Ottawa.

Rice, E.F. (1975) *Building in the North*. Fairbanks, Alaska: Geophysical Institute, University of Alaska.

U.S. Army Corps of Engineers (1976) Handbook of energy conservation measures for fixed facilities. Washington, D.C.: U.S. Government Printing Office.

APPENDIX A: HEATING SYSTEM COSTS ($/10⁶ Btu).

Site	Fuel*	Operation	Maintenance and repair	Capitalization	Total OMC	Total
Ft Richardson	1 0	—†	—	—	1 9	2 9
Juneau CGS	8 4	–	—	—	4 0	12
Ft Wainwright	2 1	1 4	0 52	0 46	2 3	4 4
Ft Greely	9 5	—	—	0 34	1 5	11
Kotzebue AFS	12	—	—	—	5 8**	18
Ft Yukon AFS	12	—	—	—	5 8**	18
King Salmon AFS	11	—	—	—	4 5**	16
Galena AFS	12	—	—	—	5 3**	17
Tin City AFS	12	4 5	0 04	0 07	4 6	17
Cape Lisburne AFS	12	1 3	0 02	0 07	1 4	13
Sparrevohn AFS	15	8 3	0 10	0 11	8 5	24
Adak NS	14	2 2	0 55	1 2	4 0	18

* Includes conversion efficiency and reflects 1980 price increase expressed in uninflated 1979 dollars

† Blanks indicate unavailable figures

** Estimate

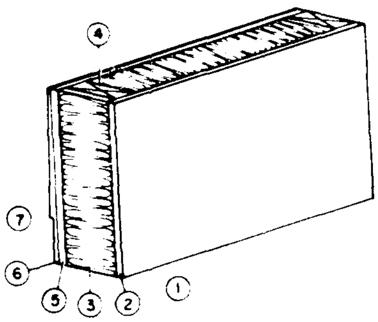
APPENDIX B: PRESENT WORTH FACTORS (PWFs).

Cost component	Escalation rate (%)	Conventional PWFs (n = 25, i = 10%) 1979	1984	1989	1999	Conservative PWF (n = 30, i = 3%) 1979
Fuel oil	8	19 8	29 1	42 8	92 3	67 9
Natural gas	8	19 8	29 1	42 8	92 3	67 9
Coal	5	14 4	18 4	23 5	38 2	41 0
OMC	0	9 07	9 07	9 07	9 07	—

APPENDIX C: BASE CASE AND INCREMENTAL THERMAL PROPERTIES.

These diagrams represent the construction and thermal resistances of the building elements analyzed For each element there is a base case, representing the minimum thermal properties assumed, and a means for increasing insulation by increments For a stud wall the framing method changes with the insulation thickness For other elements the insulation increases according to stock sizes without affecting the rest of the construction

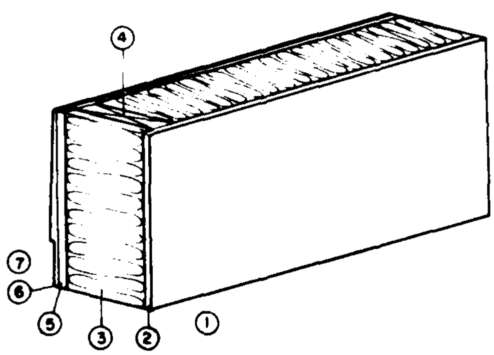
Figure C1 Wood frame construction.



Material	Thickness	R
1. Still air	–	0.68
2. Gypsum board	½ in.	0.45
3. Fiberglass insulation	3½ in.	9.97 = (14.5/16) 11*
4. Joist	3½ in.	0.41 = (1.5/16) 4.35*
5. Sheathing	½ in.	1.33
6. Steel siding	–	–
7. 15-mph air	–	0.17
Total		13.01

* Adjustments for the proportions of framing and insulation widths.

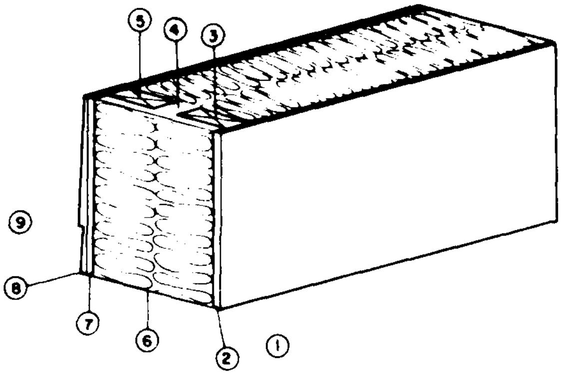
a. Base case. This construction method uses 2×4's, 16 in. on center, and has an R-value of 13.



Material	Thickness	R
1. Still air	–	0.68
2. Gypsum board	½ in.	0.45
3. Fiberglass insulation	5½ in.	17.81
4. Stud	5½ in.	0.43
5. Sheathing	½ in.	1.33
6. Steel siding	–	–
7. 15-mph air	–	0.17
Total		20.87

b. R-21 wall. The next thickest wall uses 2×6's, 24 in. on center. Its R-value is 8 larger than that of the base case (ΔR = 21–13).

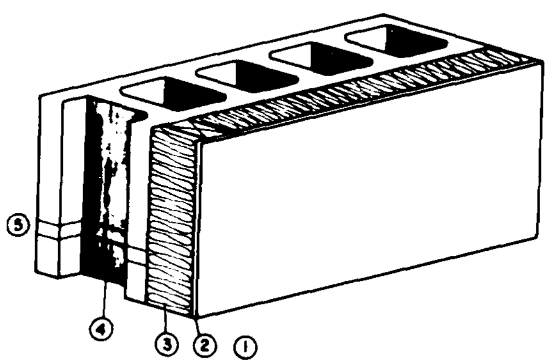
Figure C1. (cont'd). Wood frame construction.



Material	Thickness	R
1. Still air	–	0.68
2. Gypsum board	½ in.	0.45
3. Stud	3½ in.	0.27
4. Fiberglass insulation	1½ in.	0.29
5. Stud	3½ in.	0.27
6. Fiberglass insulation	8½ in.	28.13
7. Sheathing	½ in.	1.33
8. Steel siding	–	–
9. 15-mph air	–	0.17
Total		31.59

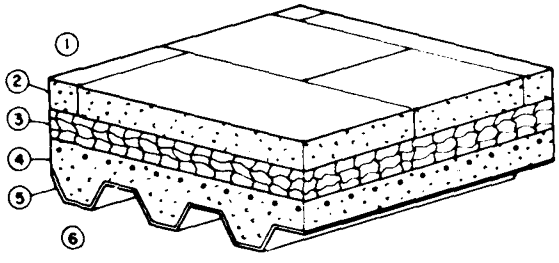
c. R-value wall. After a 2×6 wall, any thicker wall would use double rows of 2×4's, 12 in. on center, on seperate plates. The increase in R-value over a 2×6 wall would be 11 (ΔR = 32-21). Any further increase would be due to additional fiberglass insulation between the stud walls; the R-value would increase at a rate of 3.5 for each additional inch.

Figure C2. Masonry construction base case. This construction method uses 8-in.-thick concrete blocks with 2×4 furring. The base case has an R-value equivalent to that for the wood frame base case. The methods of adding thickness to the wall are similar to those for wood frame construction.



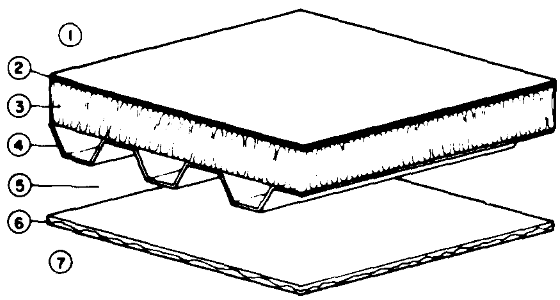
Material	Thickness	R
1. Still air	–	0.68
2. Gypsum board	½ in.	0.45
3. Fiberglass insulation & furring	3½ in.	10.38
4. Concrete block	8 in.	1.72
5. 15-mph air	–	0.17
Total		13.4

Figure C3. PRM roof base case. Additional insulation would be extruded polystyrene which would increase the R-value by 4 for each inch.



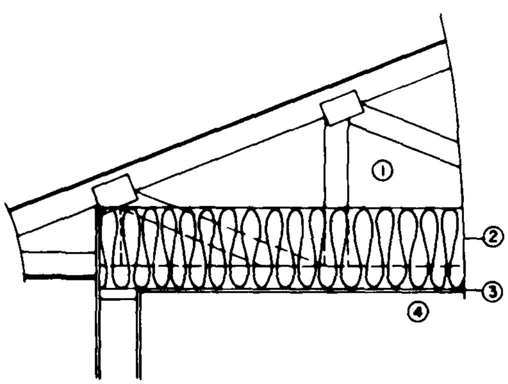
Material	Thickness	R
1. 15-mph air	–	0.17
2. Concrete paving block	2 in.	0.70
3. Extruded polystyrene	2 in.	8.00
4. Light-wt. concrete	2 in.	2.22
5. Steel deck	–	–
6. Still air	–	0.83
Total		11.92

Figure C4. BUR base case. Additional insulation would be rigid fiberglass which would increase the R-value by 2.8 for each inch.



Material	Thickness	R
1. 15-mph air	–	0.17
2. BUR felts	3/8 in.	0.33
3. Rigid fiberglass	3 in.	8.33
4. Deck	–	–
5. Air space	–	0.85
6. Acoustic tile	½ in.	1.25
7. Still air	–	0.61
Total		11.54

Figure C5. Attic base case. Additional insulation would be fiberglass batts or loose fill which would increase the R-value by 2.8 for each inch.

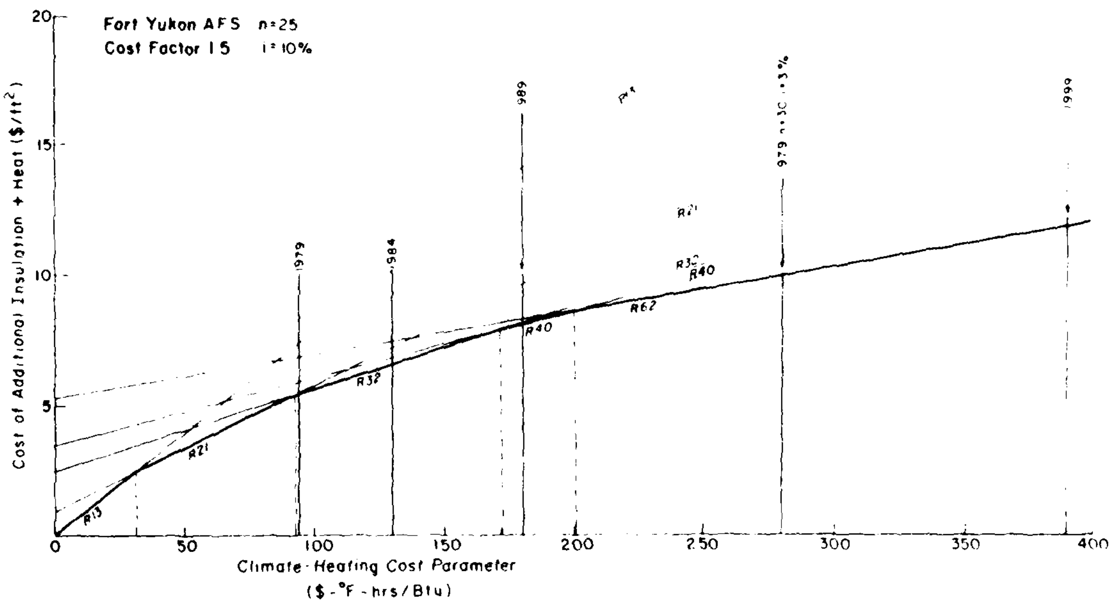


Material	Thickness	R
1&4. Still air	–	1.2
2. Fiberglass insulation	6½ in.	18.0
3. Gypsum board	3/8 in.	0.6
Total		19.8

APPENDIX D: LCC COMPARISON GRAPHS FOR WALL AND ROOF SYSTEMS

This appendix includes the life-cycle cost comparison graphs for fiberglass-insulated walls at all study sites except Ft Richardson, Juneau CGS, Ft. Wainwright and Ft. Greely, which were covered in Figures 4-7. it also includes the graphs for BURs, PRM roofs and attics at all sites

Figure D1. Graphs for fiberglass-insulated walls.



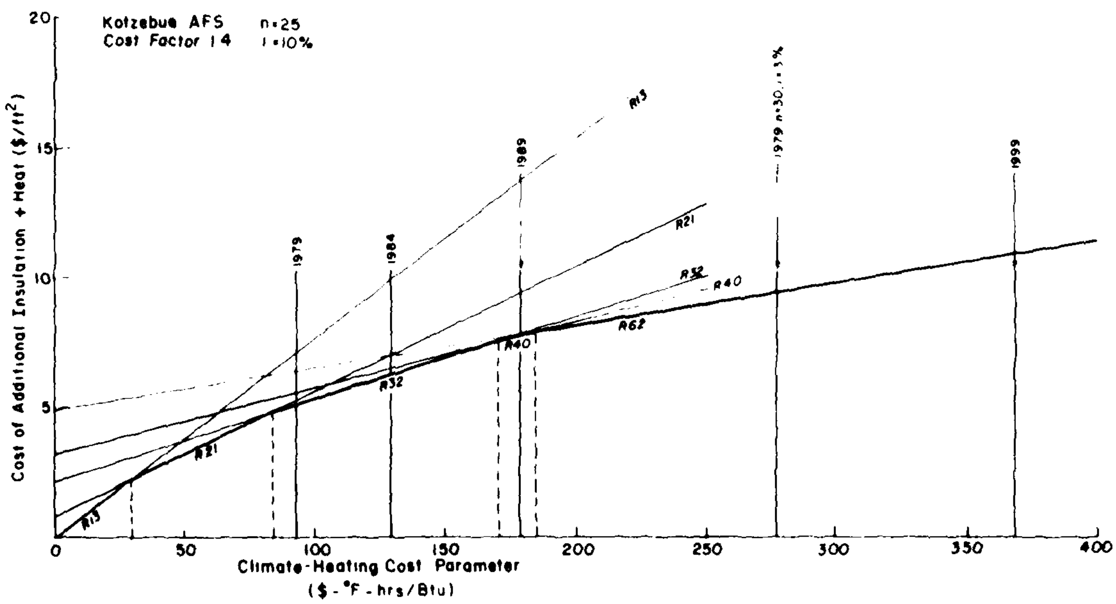


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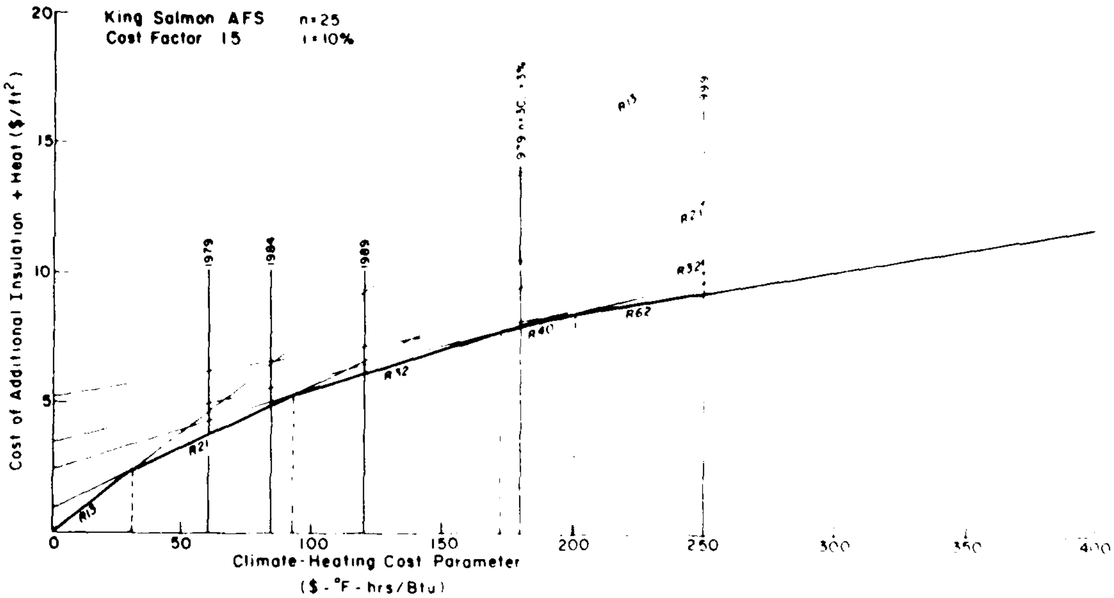
Figure D1 (cont'd). Graphs for fiberglass-insulated walls



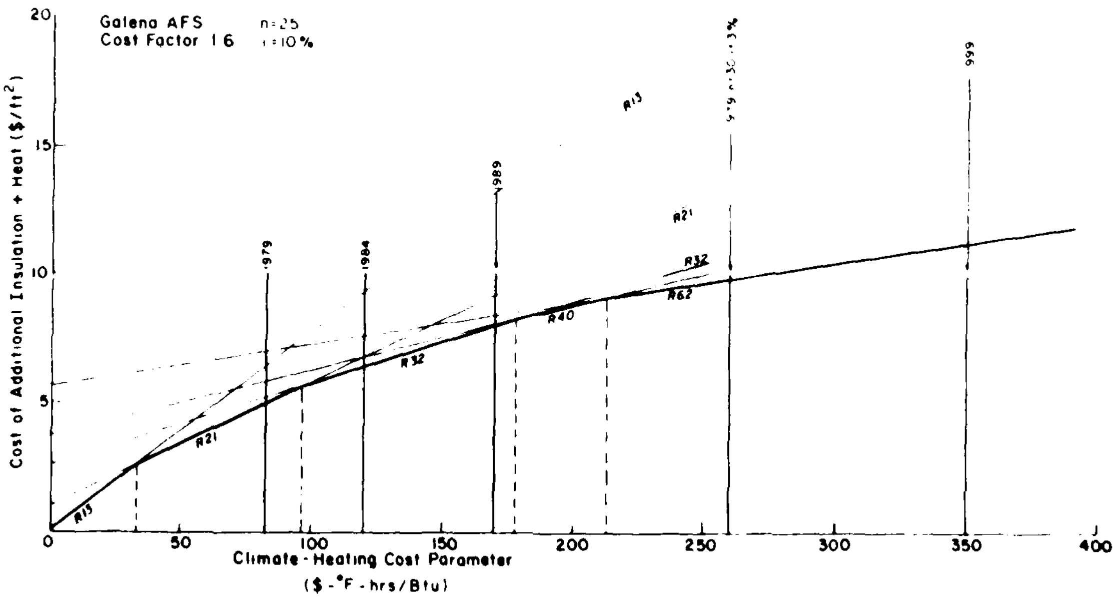
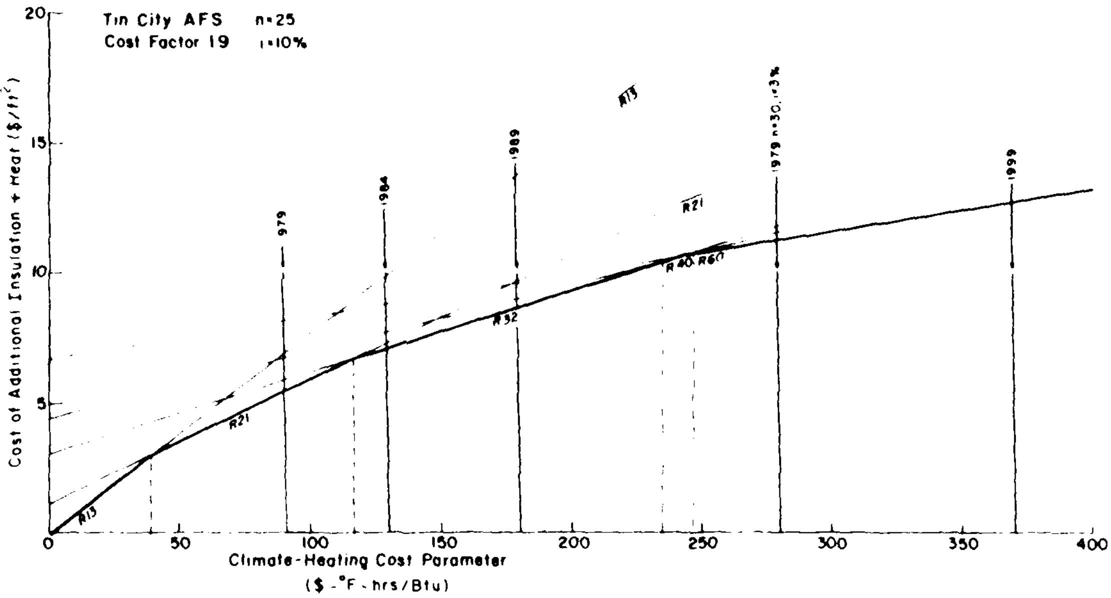


Figure D1 (cont'd)



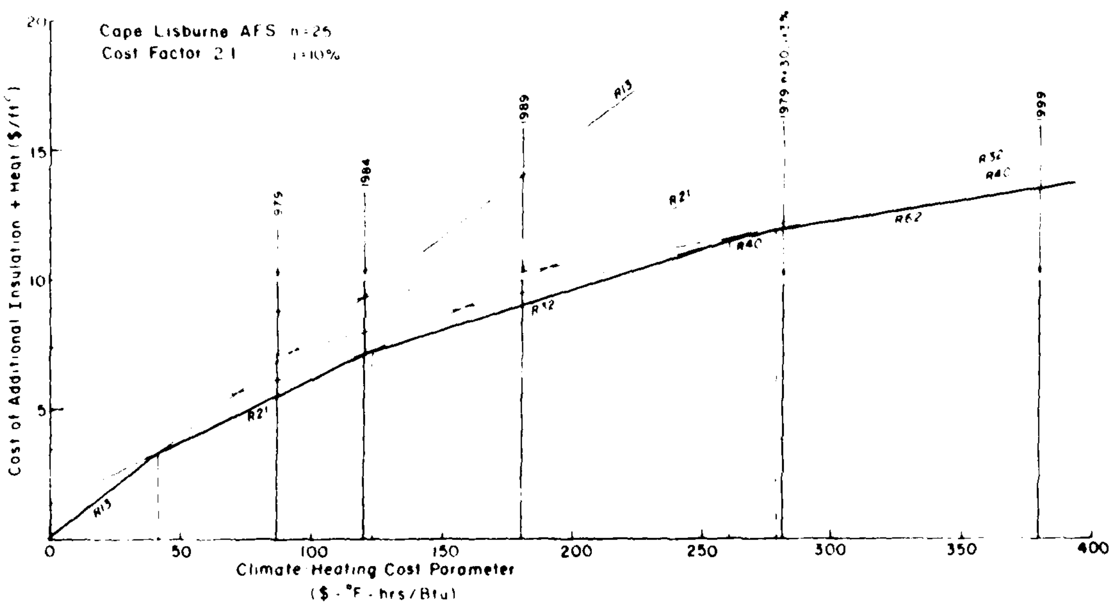
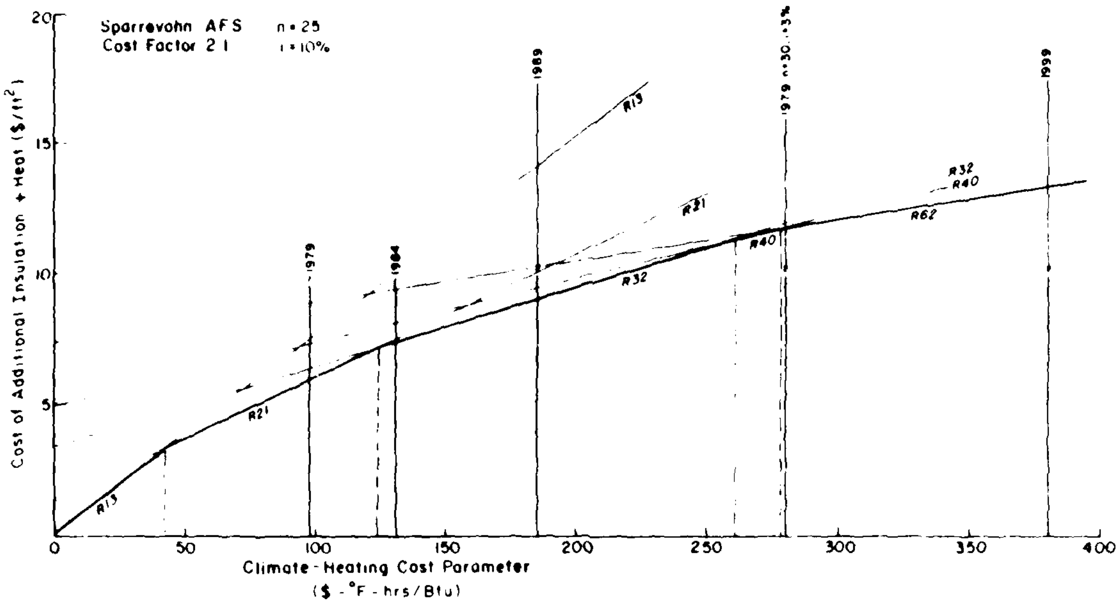


Figure D1 (cont'd). Graphs for fiberglass insulated walls



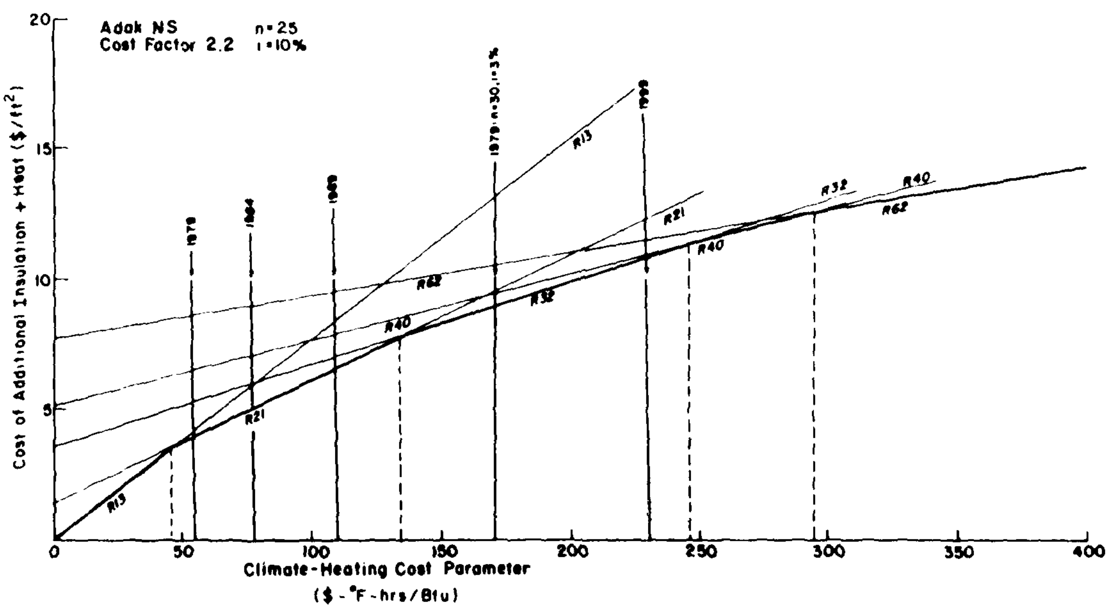
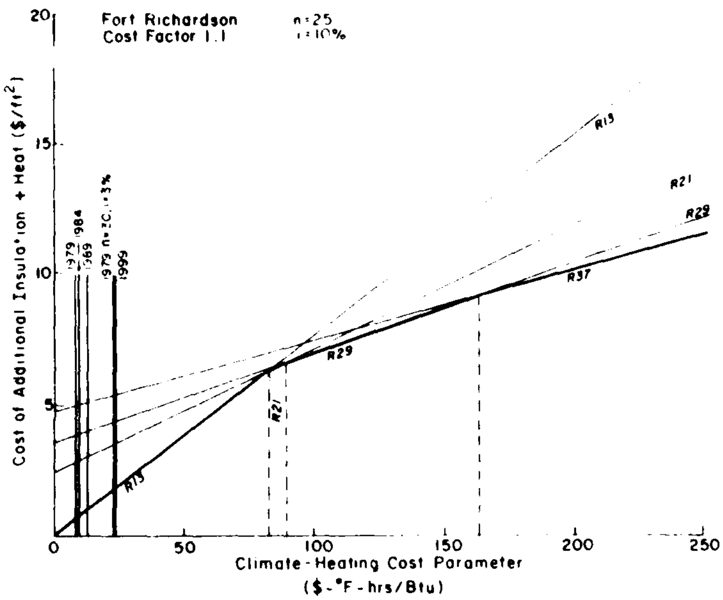


Figure D2. Graphs for PRM roofs.



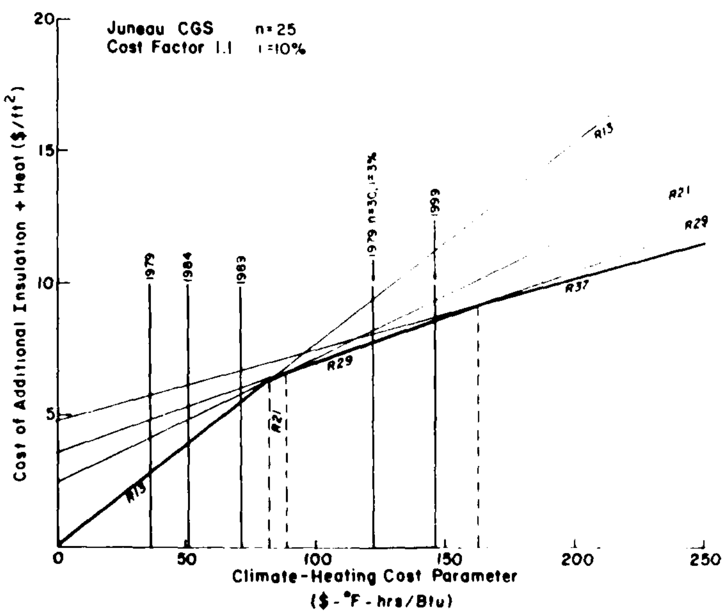
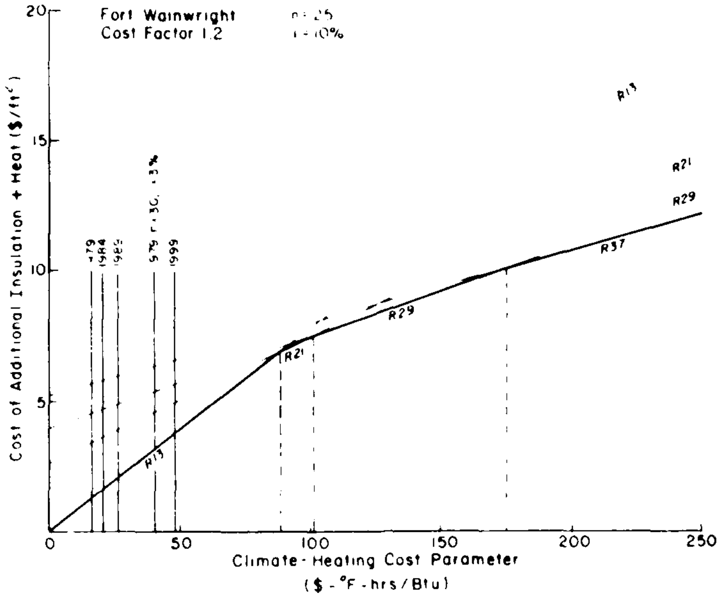
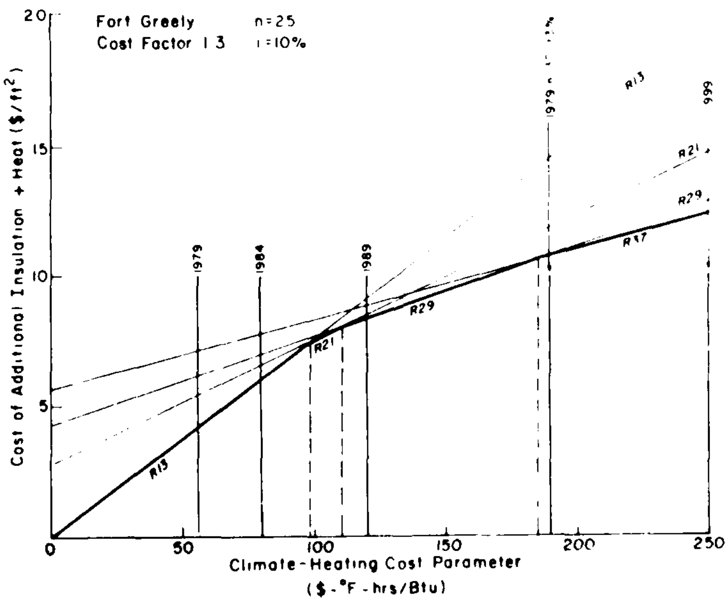


Figure D2 (cont'd). Graphs for PRM roofs.





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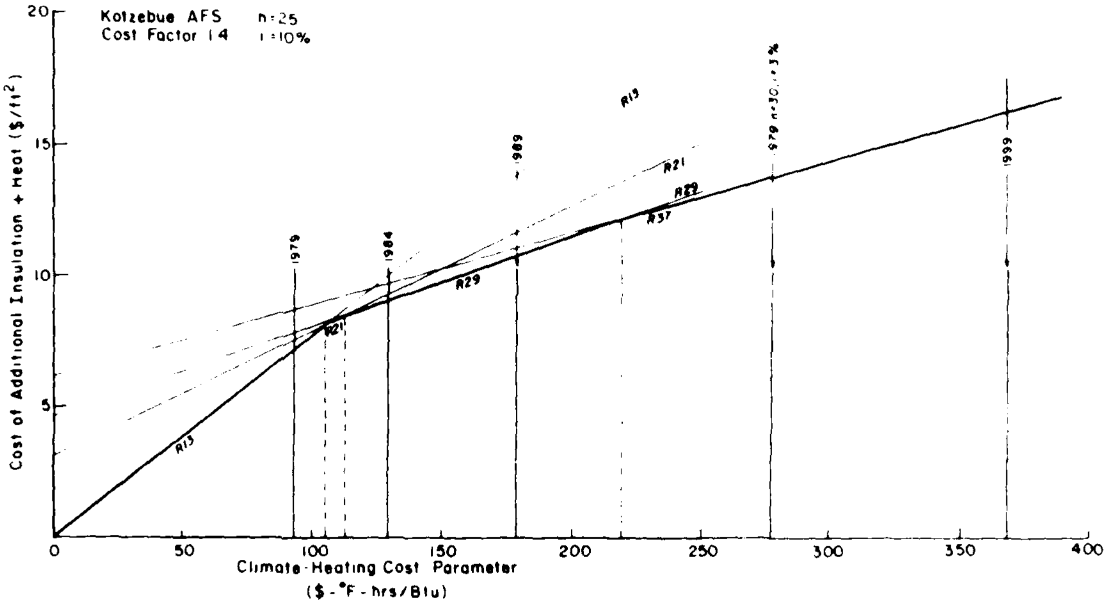


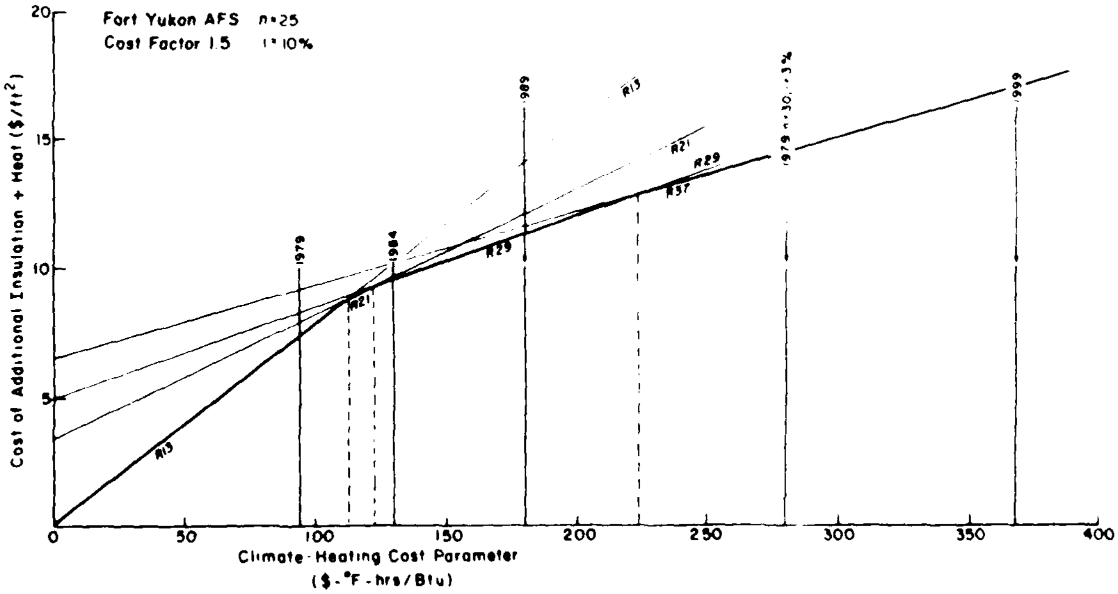
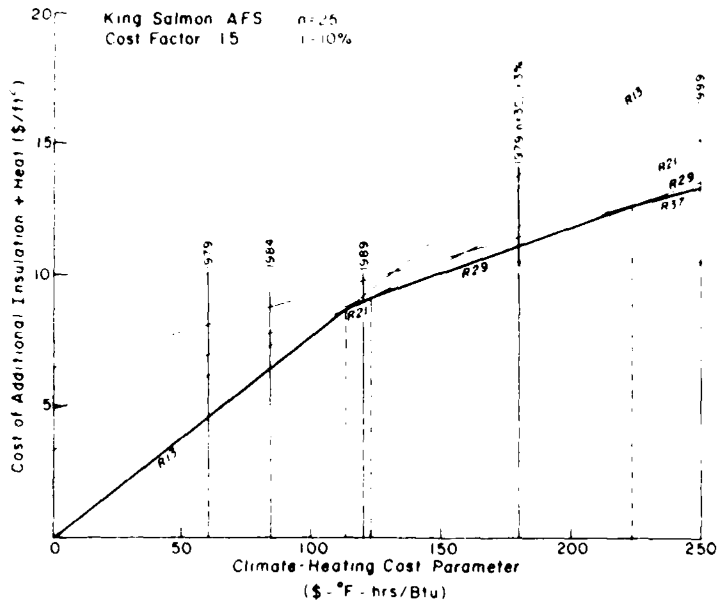


Figure D2 (cont'd). Graphs for PRM roots.



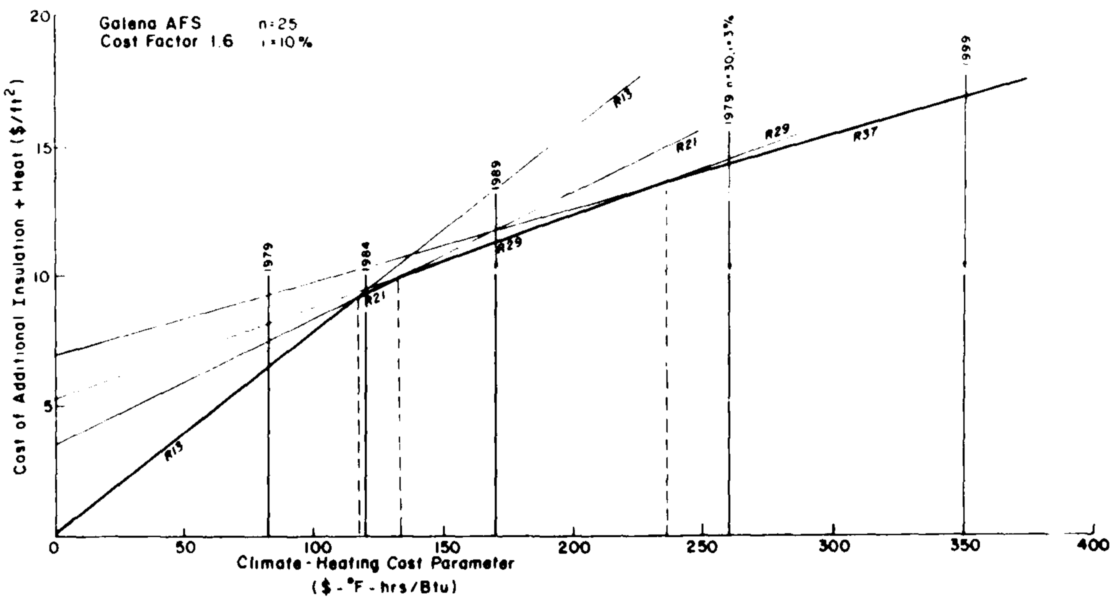
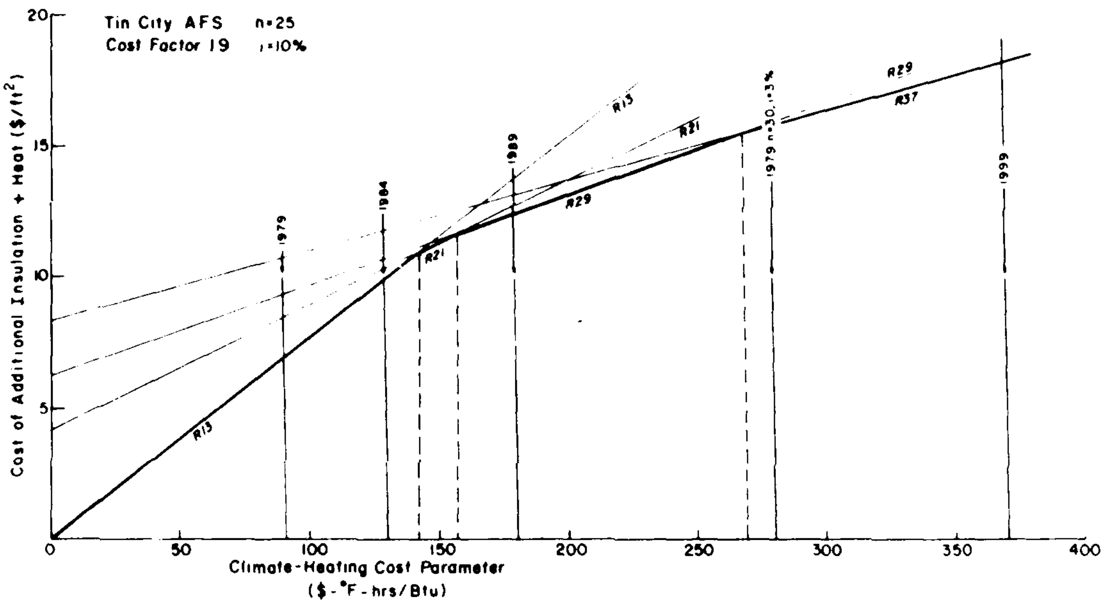


Figure D2 (cont'd)



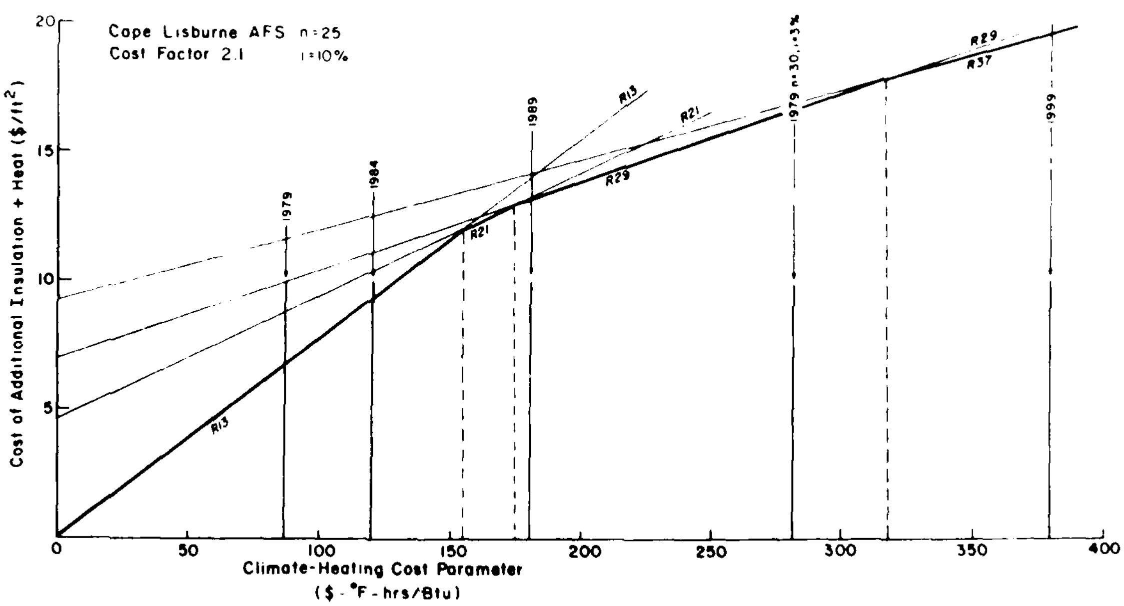
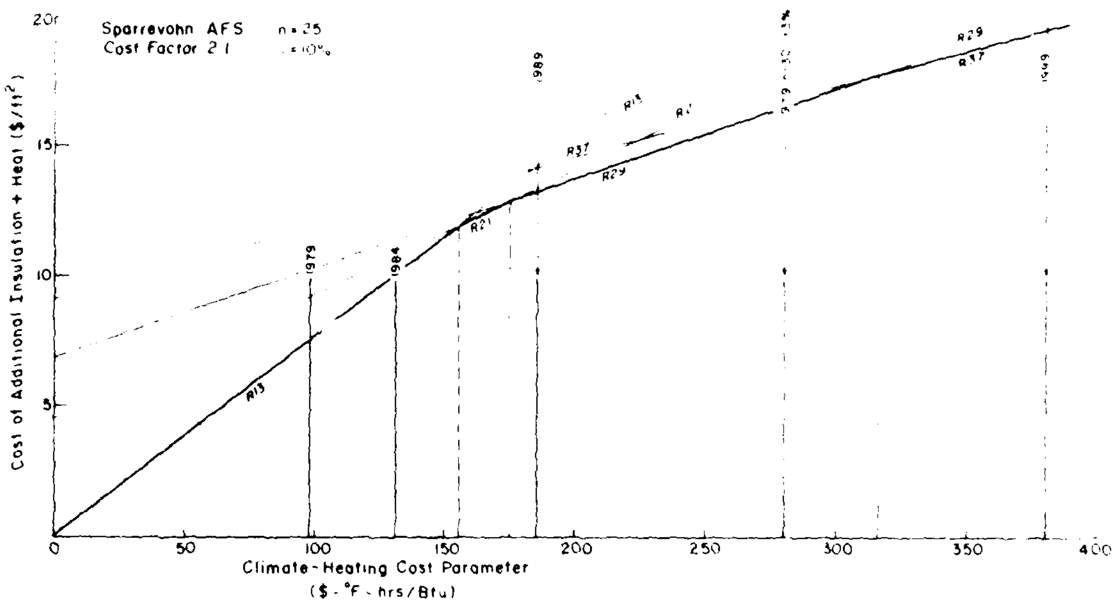


Figure D2 (cont'd) Graphs for PRM roofs



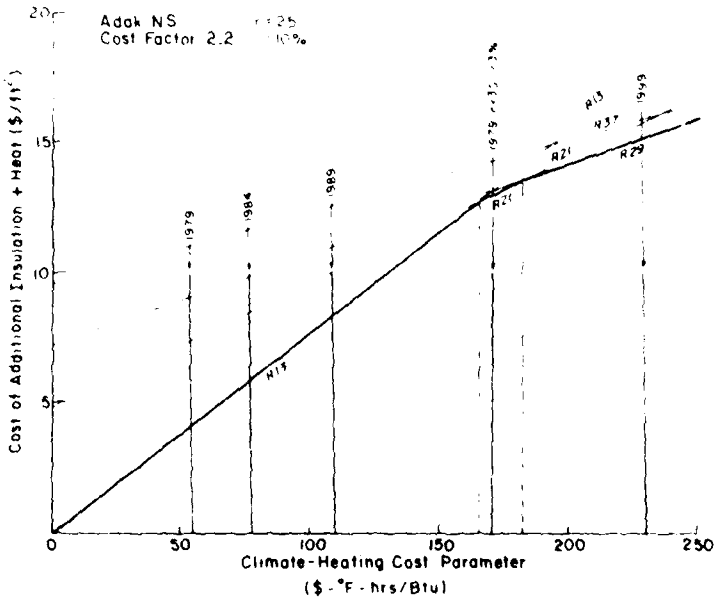
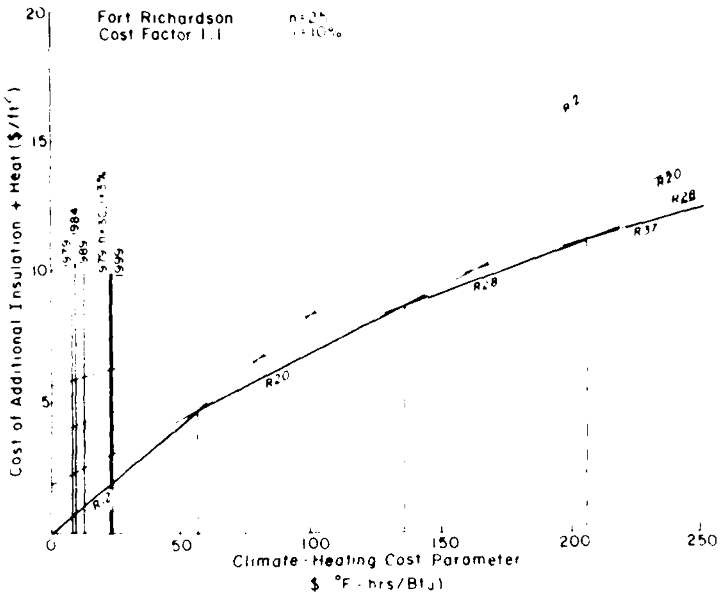


Figure D3. Graphs for BURs.



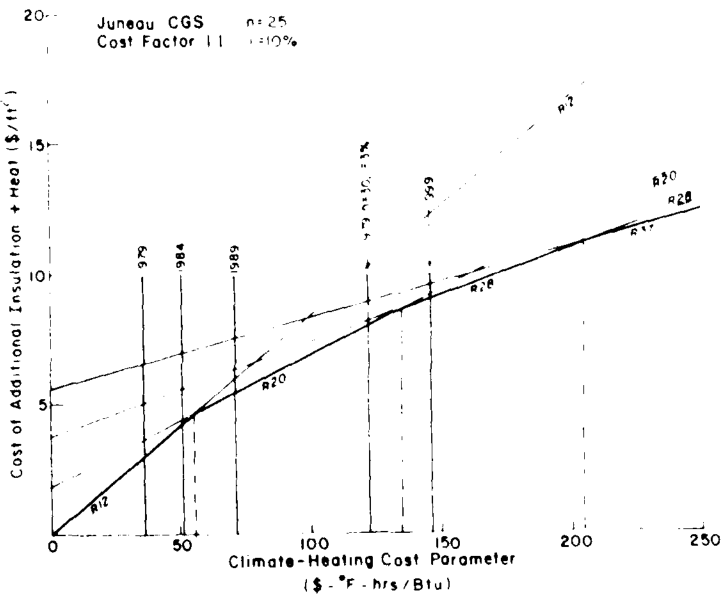
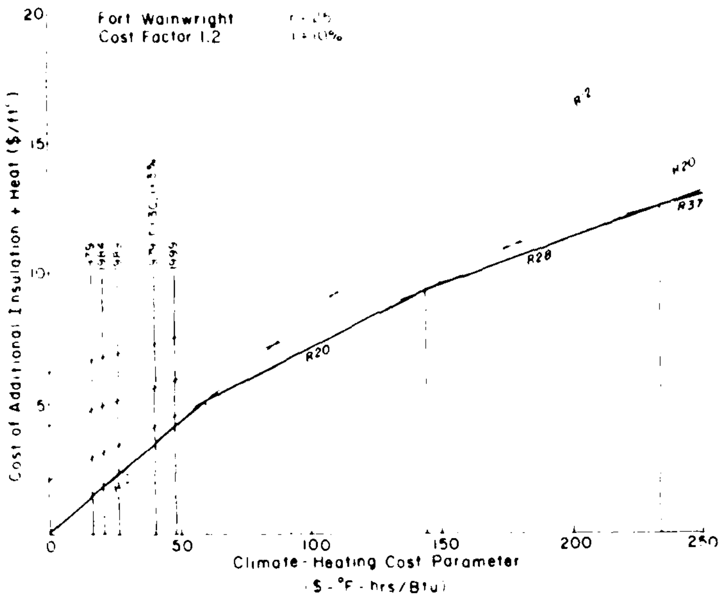
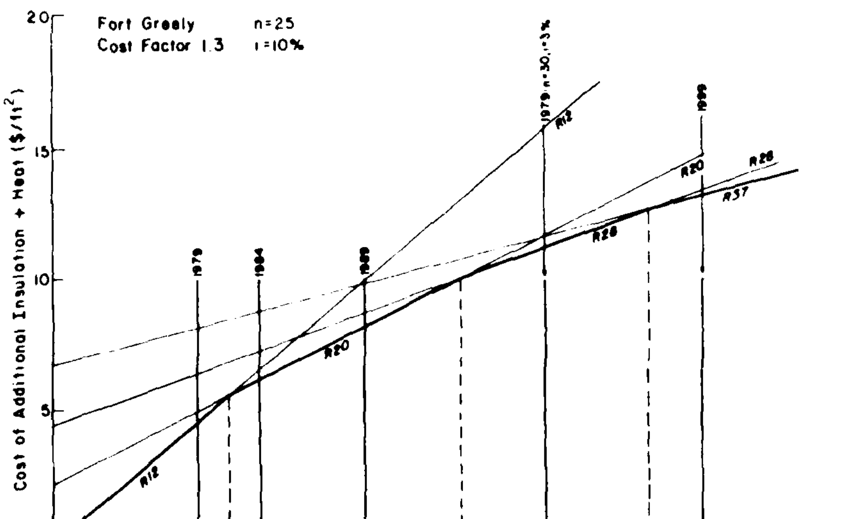


Figure D3 (cont'd). Graphs for BURs





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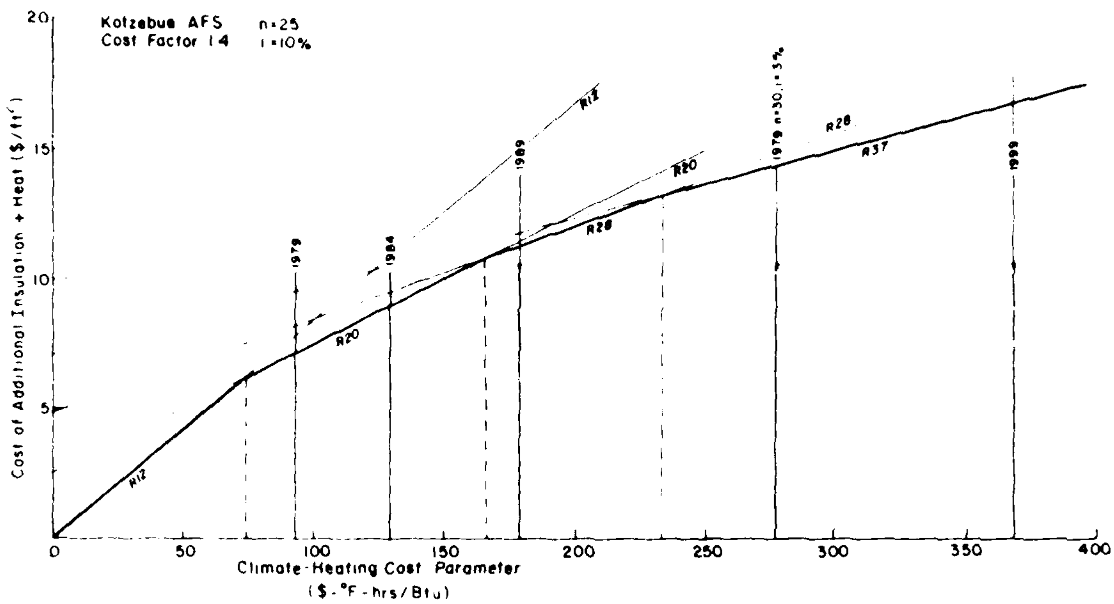

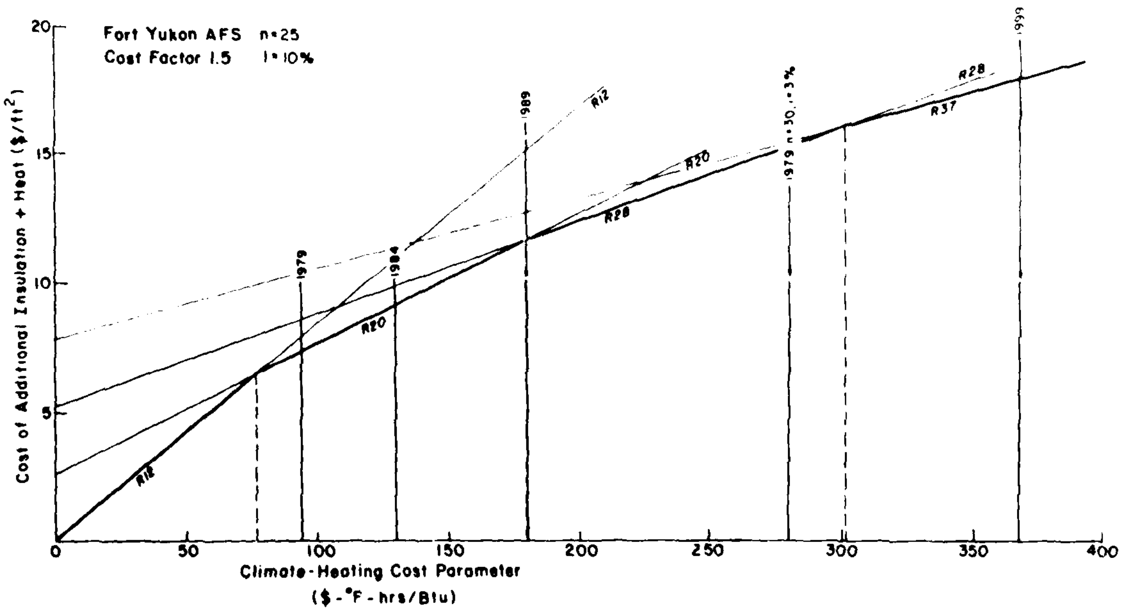

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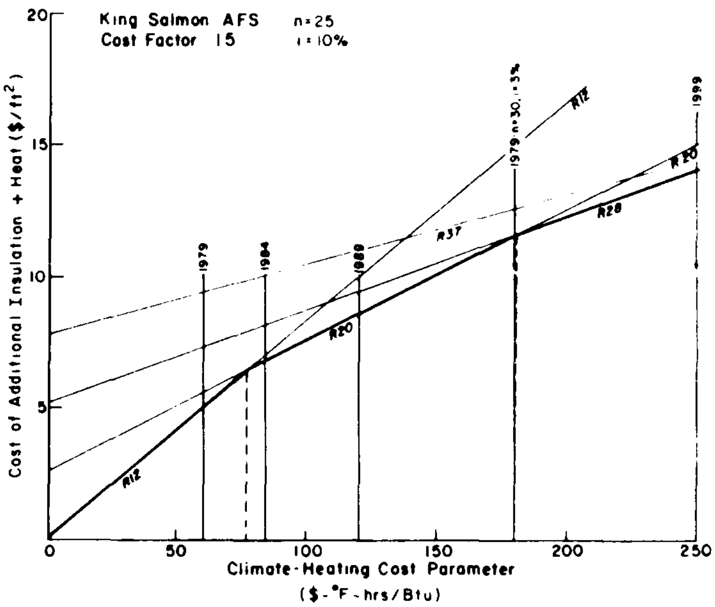
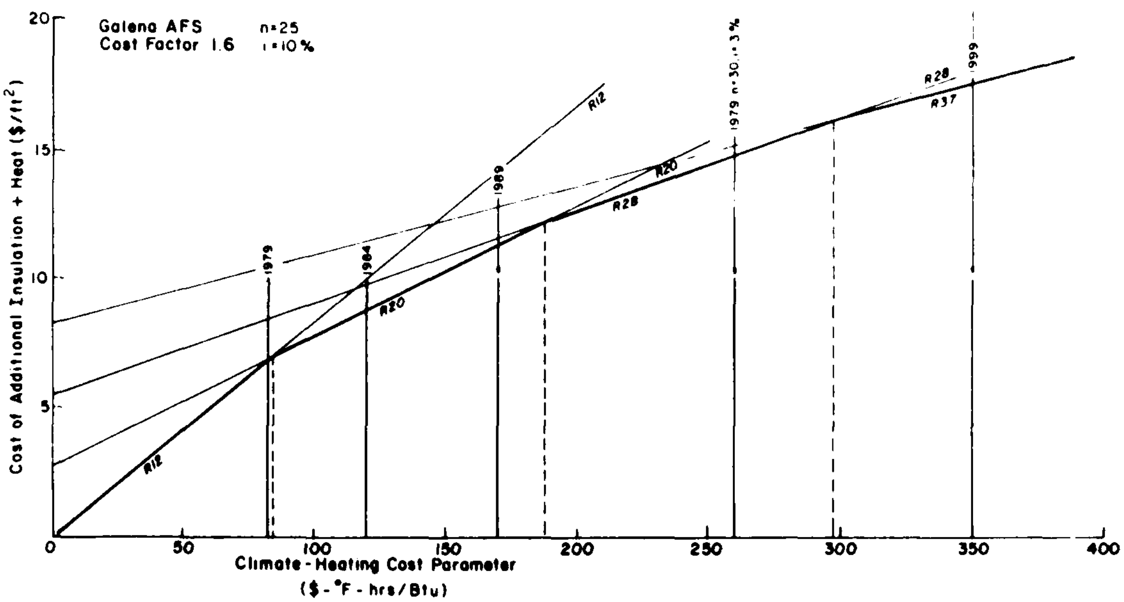
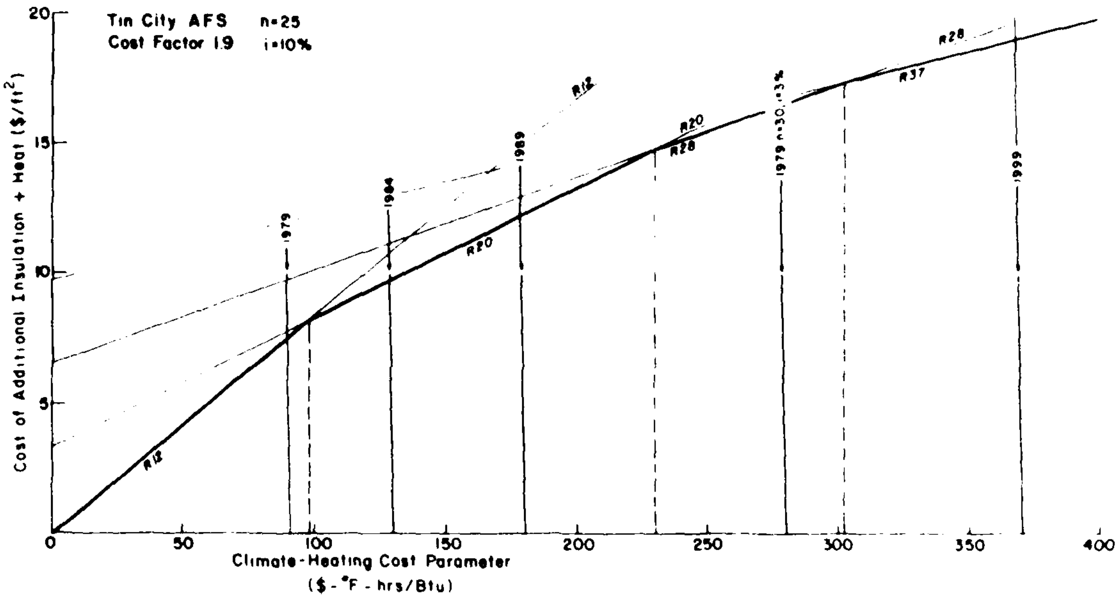





Tin City AFS n=25
Cost Factor 1.9 i=10%
Cost of Additional Insulation + Heat ($/ft²)
Climate-Heating Cost Parameter
($-°F-hrs/Btu)
R12
R20
R28
R37
1979
1984
1989
1999
1979 n=30, i=3%

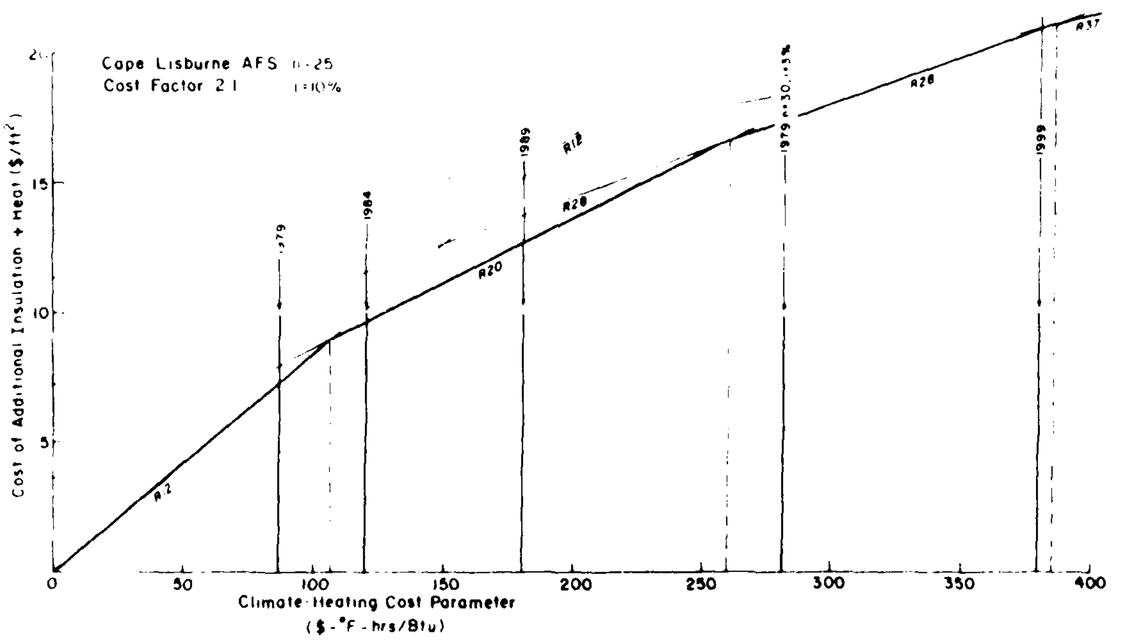
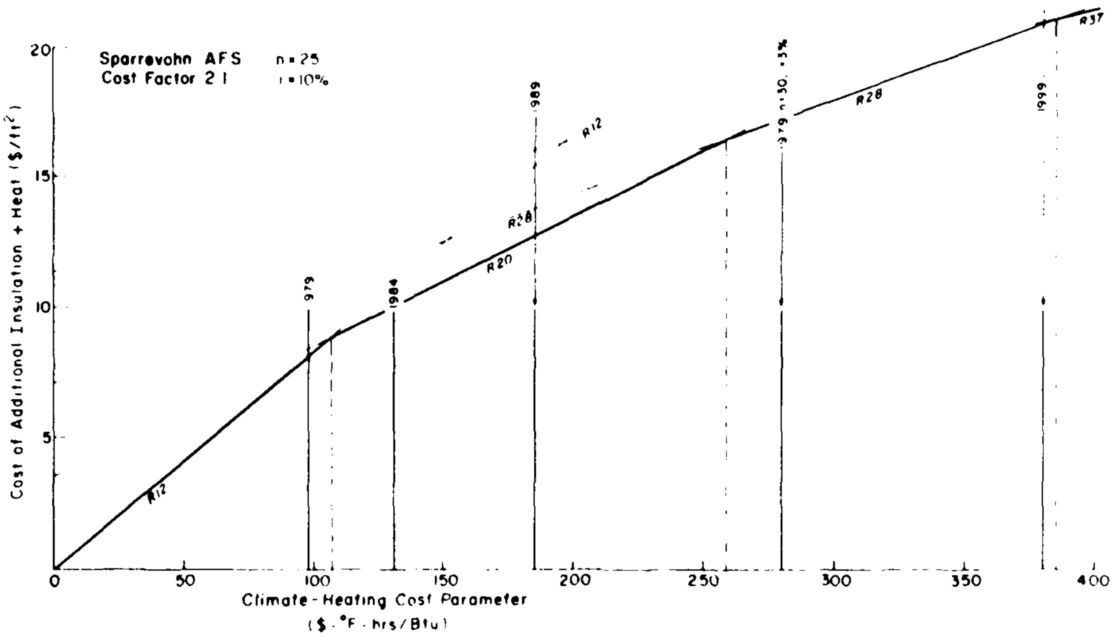

Cape Lisburne AFS n=25
Cost Factor 2.1 i=10%
Cost of Additional Insulation + Heat ($/ft²)
Climate-Heating Cost Parameter
($-°F-hrs/Btu)
R12
R20
R28
R37
1979
1984
1989
1999
1979 n=30, i=3%

Figure D3 (cont'd) Graphs for BURs



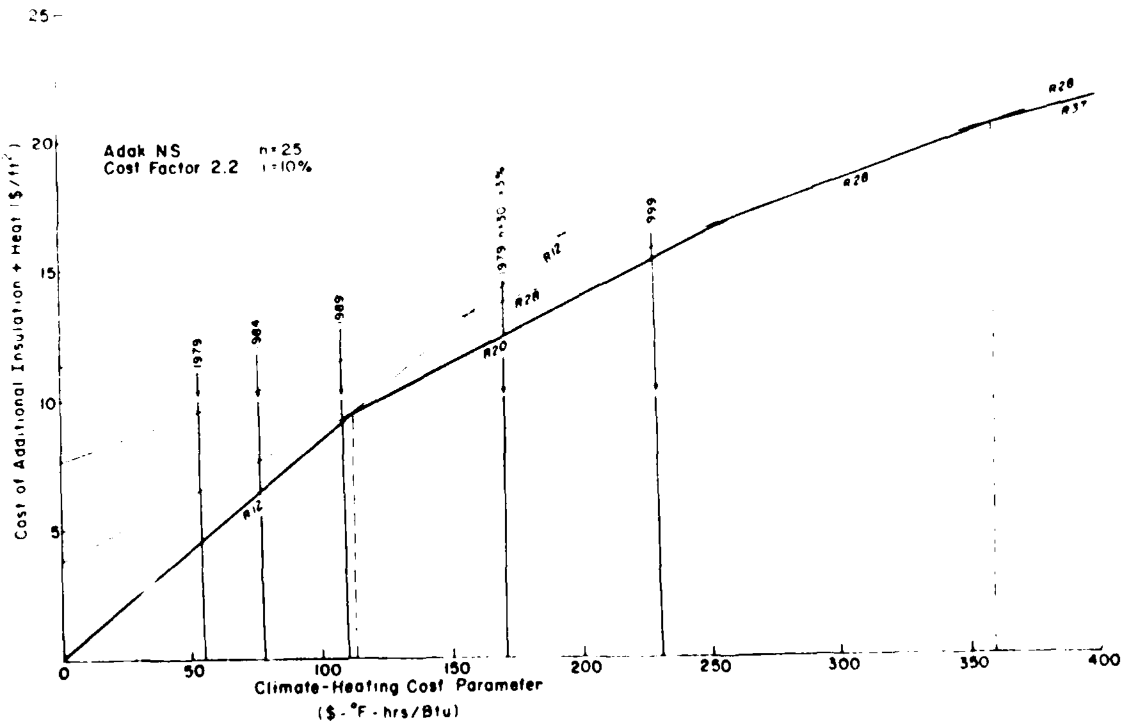


Figure D4. Graphs for fiberglass-insulated attics.

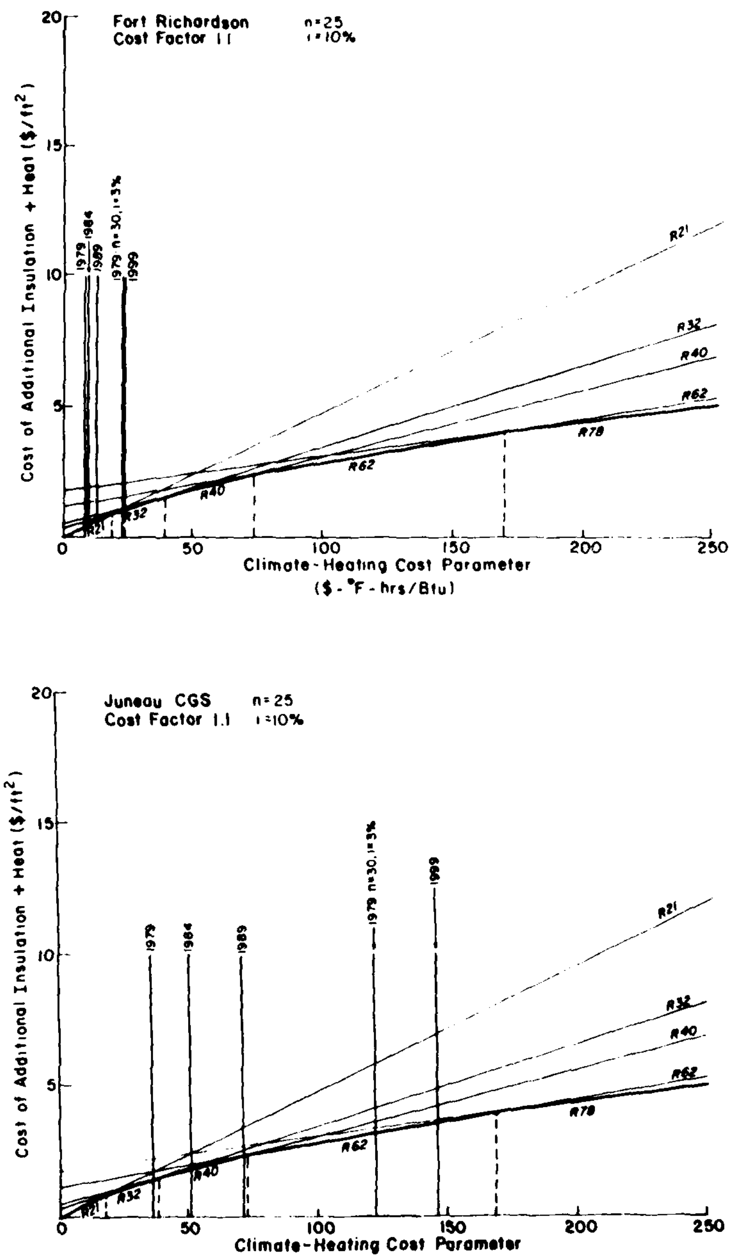
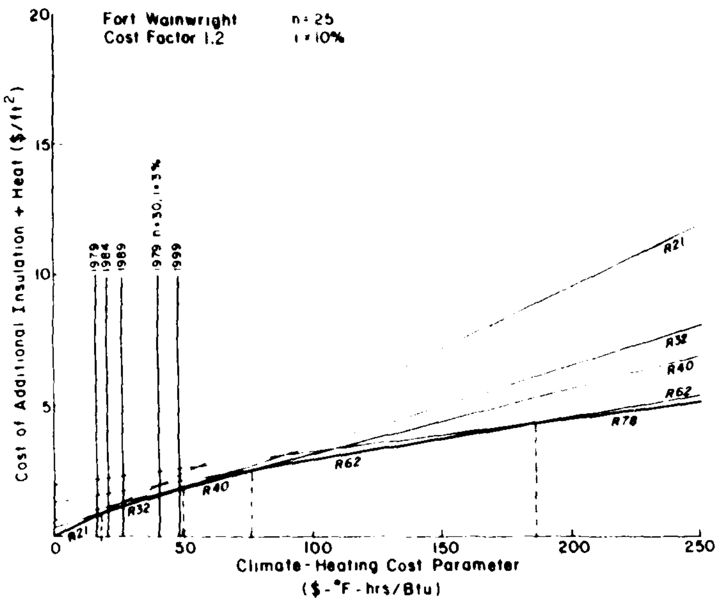


Figure D4 (cont'd). Graphs for fiberglass-insulated attics



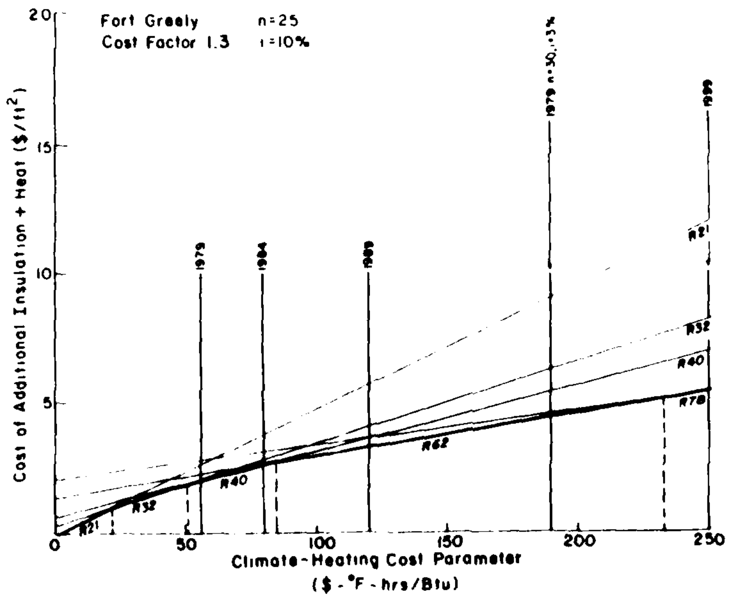
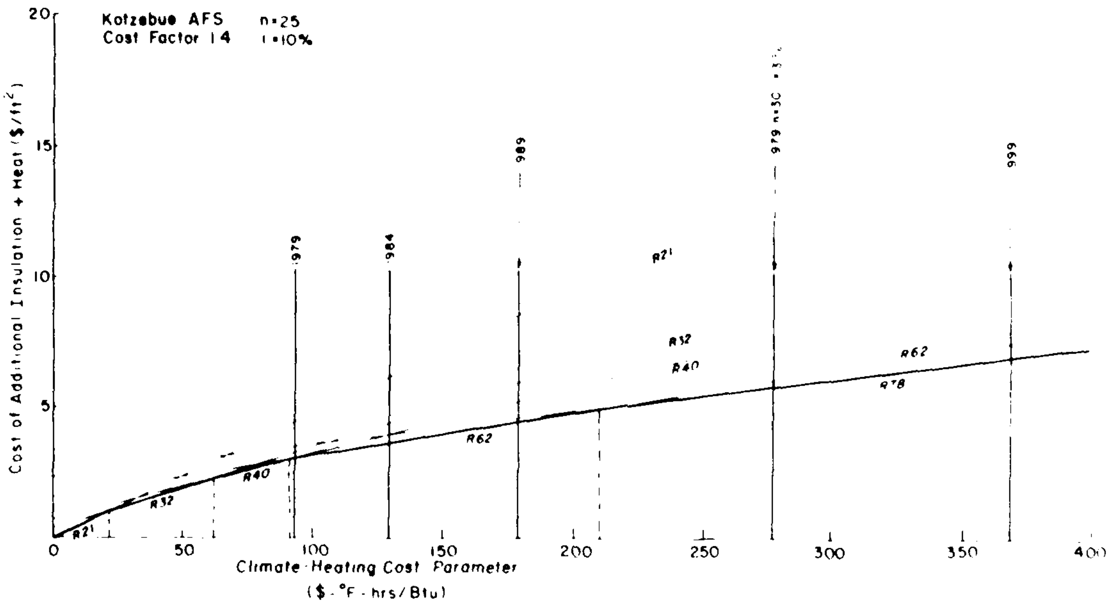


Figure D4 (cont'd).



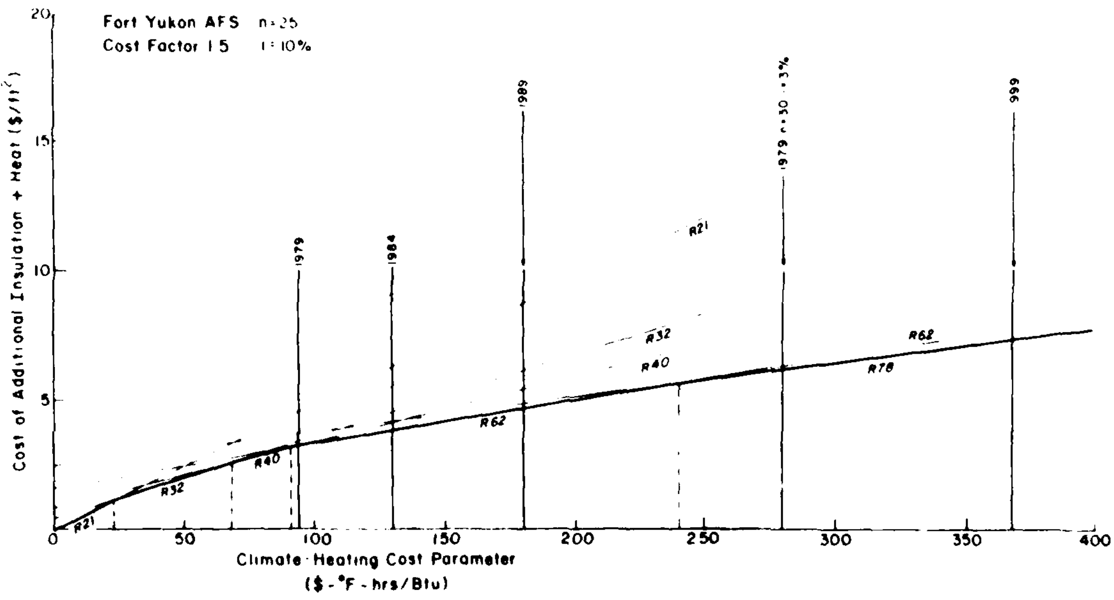
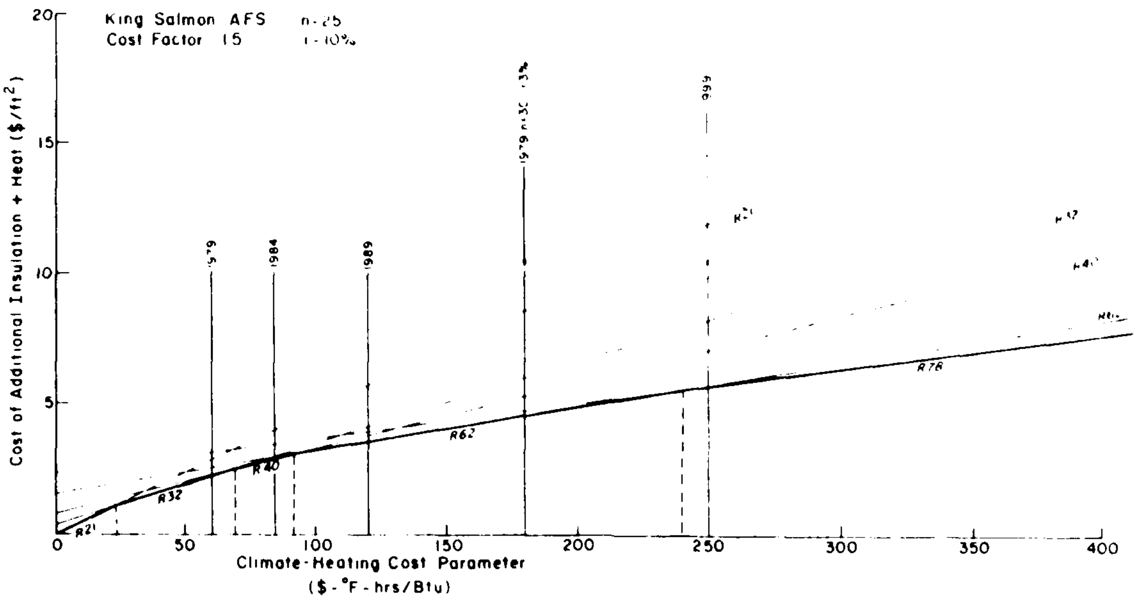
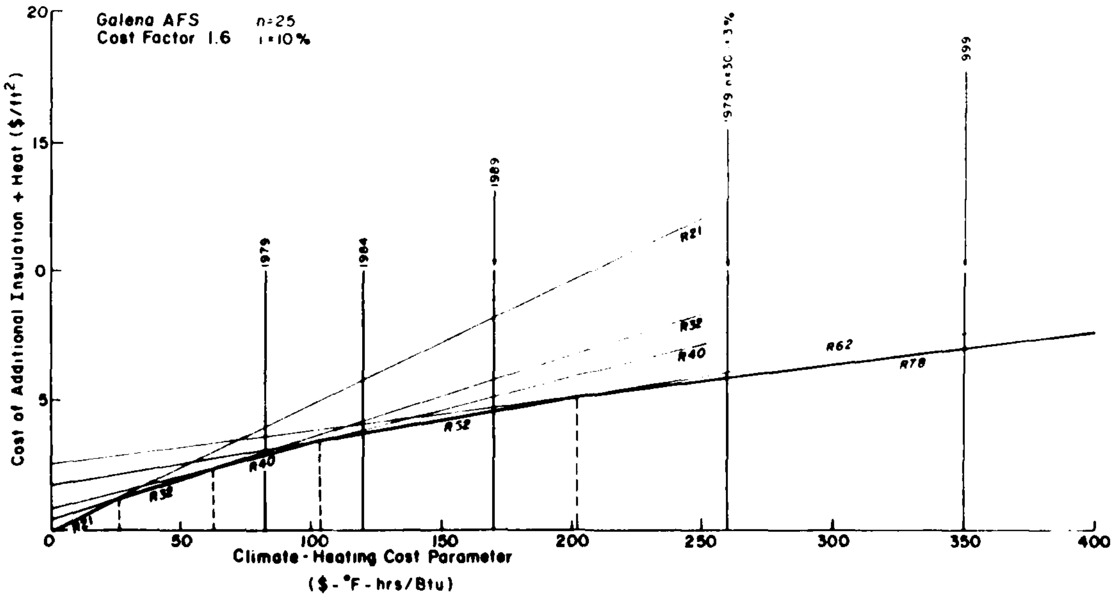


Figure D4 (cont'd). Graphs for fiberglass insulated attics





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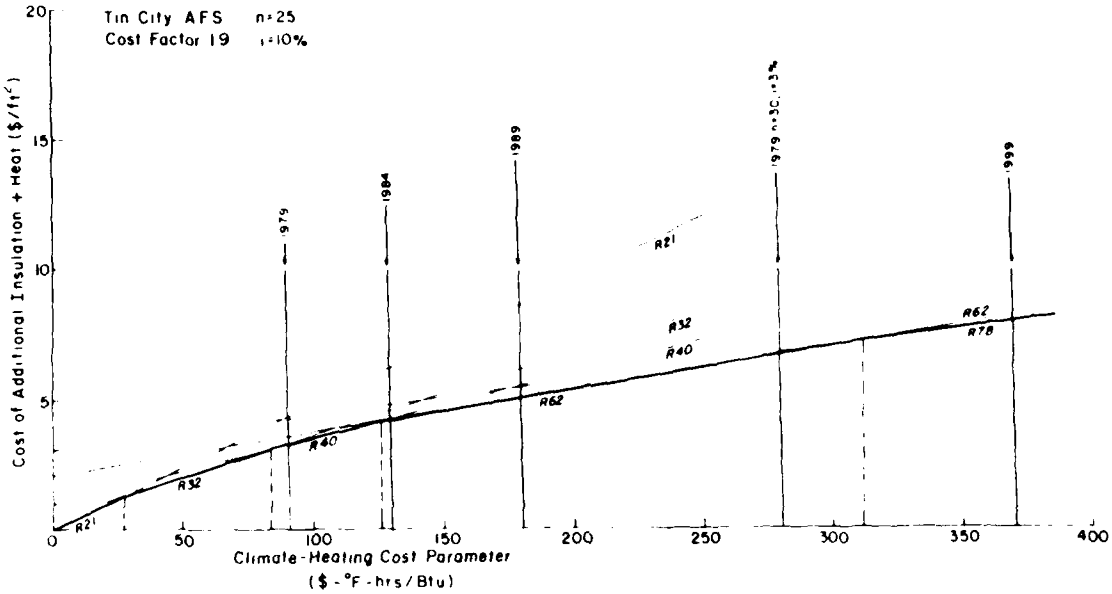


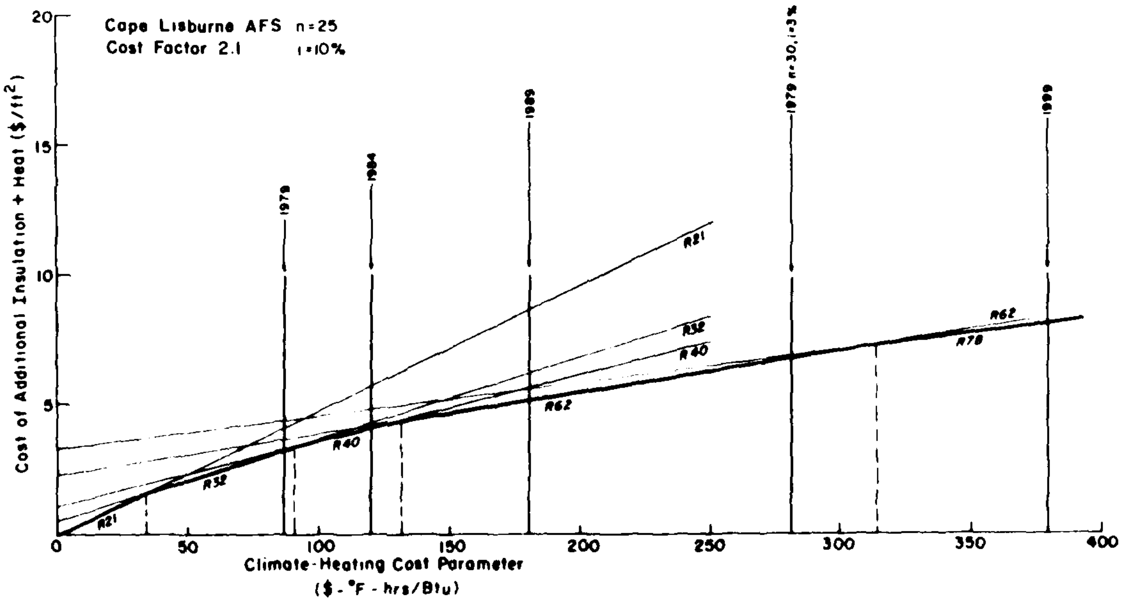
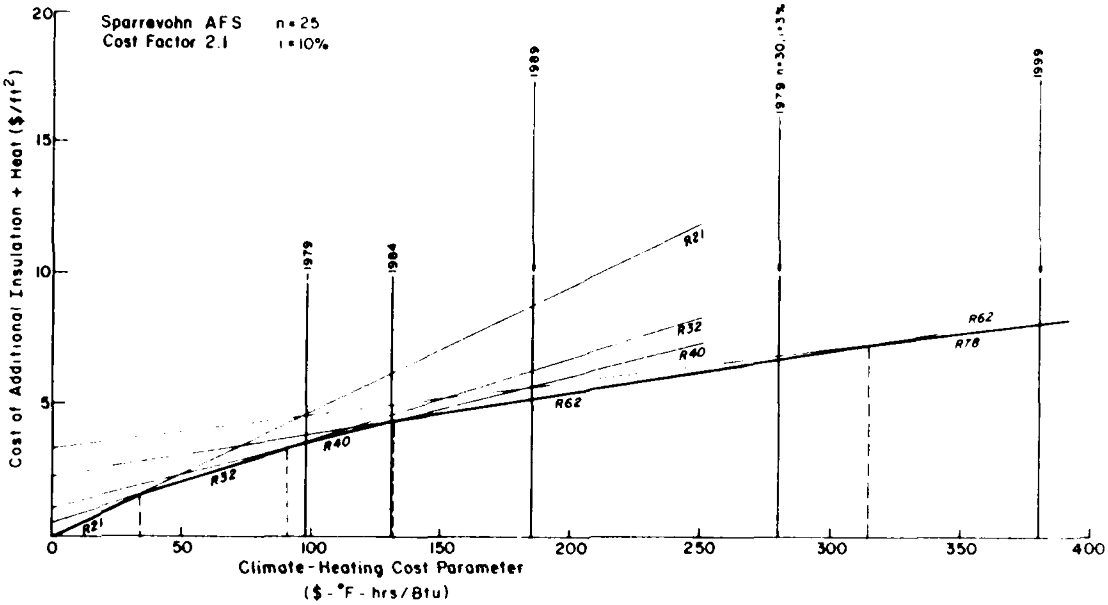
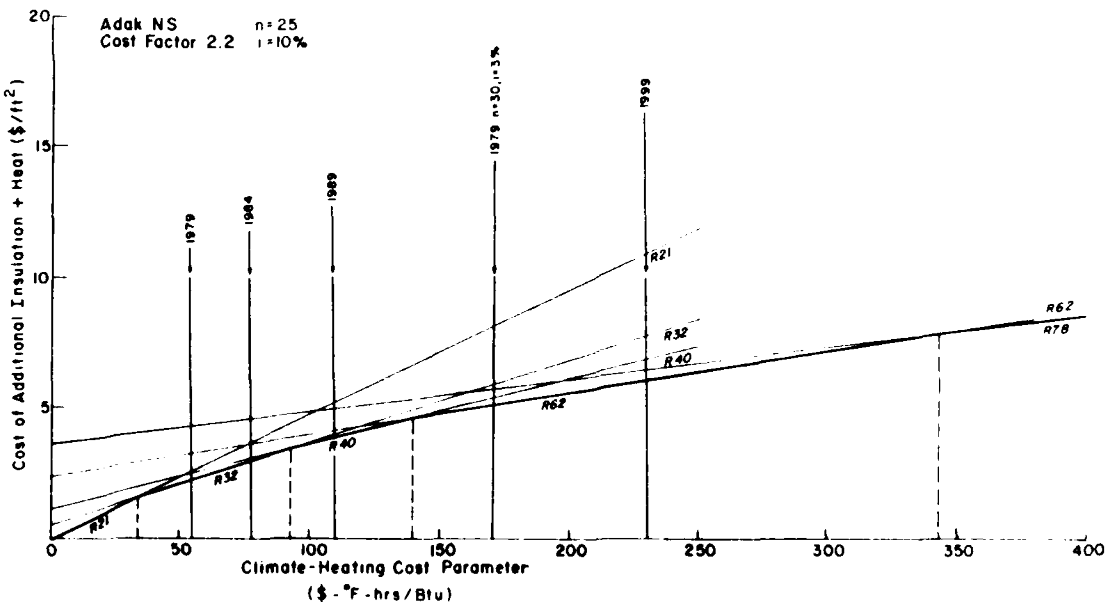


Figure D4 (cont'd). Graphs for fiberglass insulated attics





APPENDIX E: COST PENALTIES FOR ENERGY CONSERVATISM.

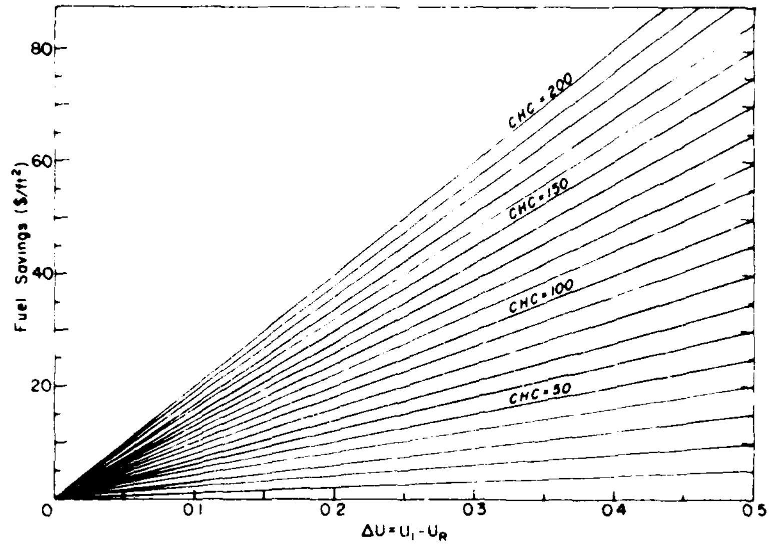
A two-story building like the one above would have a 0 5% LCC penalty for employing the conservative insulation assumption (R-32 walls, R-62 attic) in place of the conventional assumption (R-21 walls, R 32 attic) This assumes LCC cost penalties (the cost of the thicker insulation less the present worth of the fuel saved) of $0 4 ft² for attic and $0 5 ft² for walls and a $100 ft² construction cost

Table E1. Wall and attic penalties for each of the sites.

	Net LCC penalty ($ ft²)	
Site	*R-62 vs R-32 attic*	*R-32 vs R-21 wall*
1 Ft Richardson*	0 1	0 4
2 Juneau CGS	0 4	0 5
3 Ft Wainwright*	0 0	0 3
4 Ft Greely	0 7	0 8
5 Kotzebue AFS	0 2	0 1
6 Ft Yukon AFS	0 2	0 1
7 King Salmon AFS	0 3	0 5
8 Galena AFS	0 0	0 2
9 Tin City AFS	0 2	0 4
10 Cape Lisburne AFS	0 4	1 7
11 *Sparrevohn AFS*	0 3	0 5
12 Adak NS	0 1	0 3

* R-32 vs R-21 attic, R-21 vs R-13 wall

APPENDIX F: GRAPHIC AID FOR FIGURING ENERGY SAVINGS FROM THERMAL IMPROVEMENTS.



Instructions

1 Calculate CHC for your facility using eq 1 Use conventional Present Worth Factors (n = 25, i = 10%) or conservative (n = 30, i = 3%) as appropriate Locate a point between two lines that bracket your CHC

2 Draw a line from the origin through your point

3 Locate ΔU (initial U-value minus U-value after reinsulating) of improvement on the horizontal axis Draw a vertical line to your CHC line and a horizontal line to the vertical axis

4 Read the energy savings on the vertical axis This is your budget for the initial cost of the improvement to pay for itself within the period n

Figure 8 demonstrates this process.

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A facsimile catalog card in Library of Congress MARC format is reproduced below.

Flanders, Stephen N.
Least life-cycle costs for insulation in Alaska / by Stephen N. Flanders and Harold J. Coutts. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1982.
vi, 54 p., illus.; 28 cm. (CRREL Report 82-27.)
Prepared for Office of the Chief of Engineers by U.S. Army Cold Regions Research and Engineering Laboratory under DA Project 4A762630AT42.
Bibliography: p. 16.
1. Alaska. 2. Cost analysis. 3. Economic analysis. 4. Insulation. 5. Life cycle costs. 6. Thermal insulation. I. Coutts, Harold J. II. United States. Army. Corps of Engineers. III. Cold Regions Research and Engineering Laboratory, Hanover, N.H. IV. Series: CRREL Report 82-27.

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